

RESPONSE NUMBER UNDER A FIXED-INTERVAL
SCHEDULE OF REINFORCEMENT

A THESIS

Presented to

The Faculty of the Division of Graduate Studies

By

George David Gentry

In Partial Fulfillment

of the Requirements for the Degree

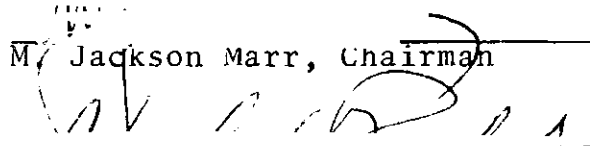
Doctor of Philosophy in the School of Psychology

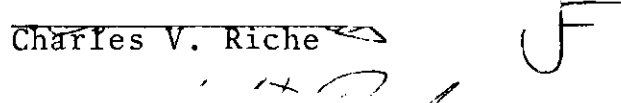
Georgia Institute of Technology

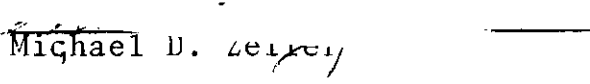
June, 1978

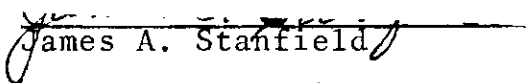
RESPONSE NUMBER UNDER A FIXED-INTERVAL
SCHEDULE OF REINFORCEMENT

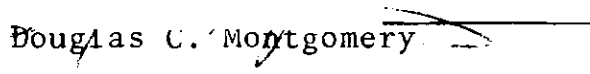
Approved:


M. Jackson Marr, Chairman


Charles V. Riche


Michael D. Leary


James A. Stanfield


Douglas C. Montgomery

Date approved by Chairman _____

TABLE OF CONTENTS

	Page
ACKNOWLEDGMENTS	iii
LIST OF TABLES	iv
LIST OF ILLUSTRATIONS	v
SUMMARY	vi
Chapter	
I. INTRODUCTION	1
Fixed-Interval Responding	
Direct and Indirect Variables	
Stereotypic Behavior under Fixed-Interval Schedules	
Dynamic Changes of Behavior under Fixed-Interval Schedules	
II. STATEMENT OF THE PROBLEM	29
III. METHODS	37
Subjects	
Apparatus	
Procedure	
IV. RESULTS	42
Response Rate and Quarter Life	
Autocorrelations	
Response Rates with Added Stimuli	
Clock Performance	
Cumulative Records	
V. DISCUSSION	62
Responses Per Reinforcer	
Response Number	
Clock Stimuli	
Conclusions	
Recommendations for Future Research	
REFERENCES	69

ACKNOWLEDGMENTS

It is difficult to express fully my gratitude to the Psychology Faculty, my fellow students, my friends, and my family who have contributed so much time and given so much encouragement in helping me to complete this degree. I hope my work in the future will justify their efforts.

My Committee not only provided many helpful comments, but did so in a very timely manner. I want to thank each of them: Drs. Charles V. Riche, Michael D. Zeiler, James A. Stanfield, and Douglas C. Montgomery.

Finally, I want to express very special thanks to Dr. M. Jackson Marr. He has contributed immeasurably to my education. My master's thesis and this dissertation could not have been completed so successfully without his guidance and advice.

LIST OF TABLES

Table	Page
1. Experimental Conditions and Number of Sessions Per Condition	41

LIST OF ILLUSTRATIONS

Figure	Page
1. Reversal of Counter Stimuli	8
2. Response Number for 200 Consecutive Intervals	17
3. Frequency Distribution for Response Number for 200 Consecutive Intervals	19
4. Lag 1 Autocorrelations for Three FI Values	20
5. Lag 1 Autocorrelations and Post-Reinforcement Pauses	22
6. Overall Response Rate and FR Requirement	24
7. Inter-reinforcement Time and FR Requirement	26
8. Overall Response Rate over Conditions	43
9. Quarter Life over Conditions	45
10. Response Rate Per FI Bin over Conditions	46
11. Lag 1 Autocorrelation over Conditions	47
12. Response Rate in Each Counter and Clock Stimulus	50
13. Response Rate in Counter and Counter Reversal	51
14. Response Rate in Counter with Correlated Reinforcement Rate . .	52
15. Response Rate in Clock and Clock Reversal	53
16. Response Number under Clock as a Function of First Stimulus Duration	55
17. Proportion of Reinforcers in the Presence of the Clock Stimuli	60
18. Cumulative Records for P70 over Conditions	61

SUMMARY

Schedules of reinforcement engender characteristic patterns of responding. The behavior produced by the fixed-interval schedule is distinguished by its variability within and across intervals. Although only one response is required after the interval has elapsed, many more responses typically occur. The initial low rate of responding in the interval is followed by an acceleration to a high steady rate at the end of the interval. Since there are no constraints on when responding must begin in the interval, there is variability in the number of responses emitted in each interval.

It has been observed in previous studies that there is some relationship between response number in one interval and response number in the next interval. There is little information available on the magnitude of this relationship; however, there are indications that a high response interval is more likely to be followed by a low response interval, and vice versa. There is also some indirect evidence that the variable "response per reinforcer" may control this fluctuation.

This experiment was designed to determine the role of response number in determining the pattern of fixed-interval maintained responding. Three major procedures were used in this experiment: 1) holding responses per reinforcer at an approximate constant value by presenting additional reinforcers at the end of the interval for higher response output, 2) providing during the interval explicit stimuli that changed as a function of the number of responses emitted

in the interval (i.e., a counter), and 3) presenting the same stimulus sequence (from the counter) independently of behavior (i.e., a clock), but yoked to previous counter performance. One additional condition used a combination of counter and approximately constant responses per reinforcer.

Overall response rate, quarter life, lag 1 autocorrelation for response number, and response rate in the presence of each of the counter stimuli showed no major change as a function of the manipulations. The lag 1 autocorrelation did show a consistent negative relationship (i.e., low response count intervals did tend to follow high response count intervals, and vice versa), however the magnitude of the effect was small. Even though rates did not change in the presence of the counter compared to standard fixed-interval maintained responding, control of the responding by the stimuli was demonstrated by reversing their order of occurrence. Under the clock stimulus condition it was found that the number of responses in each interval was determined to a large extent by the duration of the first stimulus.

It was concluded that fixed-interval maintained behavior is relatively unresponsive to the experimental manipulations that were performed. The data showed that response number can exert influence from one interval to the next, but the influence is weak. Behavior in an interval seems to be controlled largely by the stimulus conditions prevailing at the time of interval onset and thereafter possibly controlled by an irregular behavioral clock.

CHAPTER 1

INTRODUCTION

A schedule of reinforcement is a specification of relations among time, reinforcement, and responses (Morse, 1966). The most commonly studied schedules are the ratio and interval schedules with either fixed or variable parameters. Under a fixed-ratio (FR n) schedule, the reinforcer is presented following the n-th occurrence of a response; under a variable-ratio (VR n) schedule, the reinforcer is presented following the n-th occurrence of a response on the average. Under a fixed-interval (FI t) schedule, the reinforcer is presented following the first occurrence of a response after time t (usually measured from the termination of the preceding reinforcer); under a variable-interval (VI t) schedule, the reinforcer is presented following the first occurrence of a response after time t on the average (Ferster and Skinner, 1957; Morse, 1966).

These schedules (as well as others which were not described) engender characteristic patterns of responding. The fixed-ratio schedule typically controls a high steady rate with a pause following the reinforcer presentation. Fixed-interval schedules typically control a positively accelerated rate of responding throughout the interval yielding a cumulative record with the appearance of a "scallop". The variables that are responsible for these patterns have been studied extensively and will be discussed below. (See also Zeiler, 1977.)

The common element in all schedules of reinforcement is the

presentation of the reinforcer. According to the law of effect a reinforcer is a stimulus that strengthens the behavior that precedes it. While there are many possible measures of response strength, the simplest and the most commonly used is response frequency or its derived measure, response rate. Response rate has many desirable characteristics as a dependent variable, including reliability and its sensitivity to changes in the experimental situation (Skinner, 1966).

The efficacy of a reinforcer in controlling responding depends upon a number of variables including the quality, quantity, delay, deprivation, and the rate of reinforcement. The rate of reinforcement depends upon the schedule of reinforcement that is in effect and the parameter(s) of the schedule. For example, under an FI t schedule of reinforcement, the maximum rate of reinforcement is $1/t$. The actual rate of reinforcement under an FI t schedule is $1/(t+dt)$, where dt is the average time that elapses between the availability of the reinforcer and the terminal response. Under an FR n schedule, the rate of reinforcement depends upon the rate of responding: the higher the response rate, the more frequently reinforcers are presented. More precisely, the rate of reinforcement is directly proportional to the response rate with a constant of proportionality of $1/n$. Thus, the relationships between response rate and reinforcement rate for the two schedules are distinctly different.

Fixed-Interval Responding

Before describing each of the variables that may influence fixed-interval responding, the pattern itself needs to be described more fully. Typically a fixed-interval schedule is initiated by the onset of

a stimulus (e.g., keylight). The first response that occurs some time t after the onset results in the immediate delivery of the reinforcer. This cycle is usually repeated a number of times in a single session.

The pattern of responding that is generated by this procedure may be described as a positively accelerated rate of responding. Response rate is zero at the onset of the stimulus that is associated with the fixed-interval schedule or at least very low for some length of time. This pause duration depends upon a number of factors, such as the length of the interval (Dews, 1970), the magnitude of the reinforcer (Staddon, 1970), the occurrence of events prior to the stimulus onset (Shull, 1971), etc. Usually the rate of responding will continue to increase throughout the interval; however, there are exceptions to this "scallop" pattern, e.g., the break-and-run pattern (Schneider, 1969). Break-and-run describes the pattern of a pause followed by a high steady rate of responding until the completion of the interval.

Skinner (1938) described fixed-interval responding in terms of these fluctuations discussed above. Skinner enumerated four ways that responding under a fixed-interval schedule deviated from a constant response rate. First-order deviations are the long term fluctuations; second-order deviations refer to the interval-to-interval fluctuations in response rate; third-order deviations describe the scallop or fluctuations as a function of time into the interval; and fourth-order deviations are the changes on a response-to-response basis (i.e., momentary bursts and pauses in responding) and are descriptive of all schedule-maintained behavior (Zeiler, 1977).

Second- and third-order deviations found under fixed-interval responding have been studied directly in a number of experiments (Dews,

1962 and 1970; Ferster and Skinner, 1957; Herrnstein and Morse, 1958; Schneider, 1969; Shull, 1971; and Skinner, 1938). However, the determinants of these deviations are still not very well understood.

Direct and Indirect Variables

Schedules of reinforcement impose certain conditions that must be satisfied before the reinforcer is delivered. These conditions may be placed in two categories: direct and indirect variables (Zeiler, 1977).

The variables imposed directly by the schedule are called the direct variables (Zeiler, 1977). For example, under an FR \underline{n} schedule of reinforcement, a fixed number of responses is required. Thus, response number is a direct variable. Under a fixed-interval schedule, a minimum amount of time must pass before a reinforcer is delivered after a response. Thus, interreinforcer interval (or reinforcement rate) is a direct variable.

Indirect variables are those imposed by the schedule without being formally specified (Zeiler, 1977). For example, there is a minimum interreinforcer interval under an FR \underline{n} schedule; however, the schedule does not require directly a minimum interreinforcer interval. Under an FI \underline{t} schedule, even though only a single response is required, many more usually occur. Therefore, response number is an indirect variable for FI responding and may itself influence responding.

Each schedule of reinforcement engenders a characteristic pattern of responding. This characteristic pattern is the result of the action of direct and indirect variables interacting with ongoing behavior. The interaction between behavior and the direct and indirect variables produces stereotypic as well as dynamic changes in behavior (Zeiler,

1977)). The stereotypic effects follow directly from the law of effect: reinforced behaviors become more likely.

The dynamic effects are changes in behavior, the type of change depending upon the value of each of the controlling variables operating under that particular schedule.

Stereotypic Behavior Under Fixed-Interval Schedules

The stereotypic behavior engendered by a fixed-interval schedule has two primary components: the pause at the beginning of the interval and the accelerated rate of responding at the end of the interval. A number of studies have explored the direct and indirect variables that control these two components.

The pause at the beginning of the interval appears to be controlled by a complex stimulus that is associated with extinction (i.e., a period of non-reinforcement). As mentioned above, the interval is typically started with the onset of a discriminative stimulus. The onset of that stimulus is never associated with reinforcement (unless the interval is very short). Therefore it should be expected that the complex stimuli that are associated with the passage of time should initially control a very low or zero rate of responding. At a later point in the interval, these stimuli will be associated with a higher rate of reinforcement and should, therefore, control a higher rate of responding. Schneider (1969) proposed this view of fixed-interval responding: a fixed-interval schedule of reinforcement may be viewed as a tandem variable time, variable interval ($T_{and} \quad V T \quad t \quad V I \quad t$) schedule of reinforcement. That is, a variable time schedule is in effect for a variable duration followed by a variable interval schedule without an

explicit change in the stimulus conditions. The transition from the variable time component to the variable interval component is apparently controlled by the unspecified complex stimuli associated with the passage of time. This transition from the variable time to the variable interval component is assumed to be indicated by the rise in response rate, or the break point in the break-and-run patterns. (The break point is the transition point from a zero to a high response rate.)

From the preceding analysis it might be expected that if the organism were under "stronger" stimulus control associated with the passage of time, the break point or transition to a higher response rate would occur later in the interval. Such control can be provided by the use of added stimuli which change as a function of time into the interval. Such stimulus control arrangements are appropriately called "clocks". Under such an arrangement only the stimulus presented at the end of the interval would ever be associated with the presentation of the reinforcer. All other stimuli in the clock would be explicitly associated with non-reinforcement.

Ferster and Skinner (1957) arranged FI schedules with an added clock. The clock was started as a small dot of light ($1/16$ inch square). The light changed continuously throughout the interval until at the end of the interval it was a slit ($1/16$ by $3/4$ inches). Responding came under the control of the light very quickly. The smaller sizes of the slit controlled a zero rate of responding, followed by a rapid transition to a very high rate as the slit grew larger. Ferster and Skinner (1957) then demonstrated the stimulus control of the clock by reversing its direction. The larger sizes, now at the

beginning of the interval, maintained control of high response rates; the smaller sizes at the end of the interval controlled a low rate of responding. Thus, by reversing the clock an "inverted scallop" resulted. It can be concluded that the added stimuli associated with the passage of time supplanted the weaker stimulus control that is normally found under fixed-interval schedules.

Segal (1962) extended the findings of Ferster and Skinner (1957) on the effect of a clock added to FI schedules. Rather than using a continuous clock, Segal used four discrete stimuli that changed independently of behavior. Compared to an FI without the clock, responding occurred almost totally in the last quarter of the interval when the last stimulus was present. Under an FI without the clock, the responding gradually increased throughout the successive quarters of the interval. To test the control of the stimuli, Segal presented each of the four stimuli for the total duration of the interval and compared the response rates. A cumulative record from one of these test sessions is shown in Fig. 1. It can be seen that the last stimulus controlled a high rate of responding throughout the interval. Clearly, the clock stimuli had gained powerful control over the responding by being differentially associated with time in the interval.

Laties and Weiss (1966) gave further evidence of the powerful influence of an exteroceptive clock on FI responding. They alternated in an irregular fashion a fixed-interval schedule with an added clock (five discrete stimuli) with a fixed-interval schedule without added stimuli (i.e., Mult FI 5 FI 5+clock). As might be expected from the earlier results discussed above, the behavior stabilized with the clock

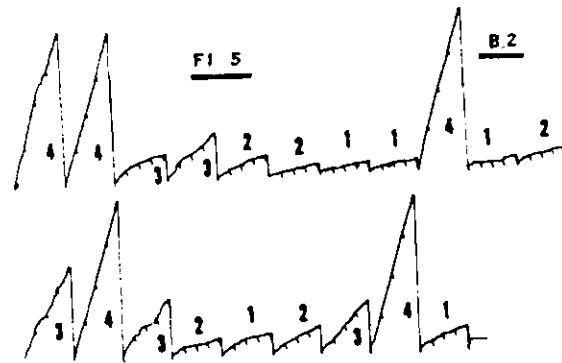


Figure 1. Reversal of Counter Stimuli (From Segal, 1962)

schedule controlling a near zero rate of responding in the first four stimuli and a high rate of responding in the fifth, while the non-clock schedule maintained a more variable pattern typical of FI responding. They then administered doses of the following drugs to determine the differential effects of the stimulus conditions: d-amphetamine sulfate, scopolamine hydrobromide, sodium pentobarbital, chlorpromazine hydrochloride, and promazine hydrochloride. Responding under the clock condition was altered little by amphetamine, scopolamine, and pentobarbital; however, these drugs did alter the responding under the FI without the clock. There was no apparent difference for chlorpromazine or promazine when comparing clock to no clock.

While it is quite clear that the added stimuli led to differential drug effects, the source of the difference is not clear. As Laties (1975) pointed out, in addition to controlling different patterns of responding, the two conditions (clock and no clock) also control different rates of responding which in themselves are also known to influence drug effects.

Another example of how added stimuli can control FI responding can be found in a study by Farmer and Schoenfeld (1966). After establishing responding under an FI 1 min to a white key light, they arranged a change in key color to green for a six-second duration. The temporal placement of the green light within the interval was varied across conditions of the experiment. When the green key light occurred during the last six seconds of the FI 1 min, the stimulus arrangement is very similar to the clock schedules described above. Under this arrangement the responding was suppressed in the early portions of the interval and was much higher in the last six seconds.

As the stimulus was moved from the last six seconds to earlier portions of the interval, responding was increasingly suppressed. Responding before and after the green light intervention was very similar to normal FI responding.

An experiment was done earlier by Dews (1962) in which stimuli never associated with reinforcement (S-deltas) were interpolated in a number of places in the interval. Dews studied an FI 500-sec schedule with an added stimulus (house light) presented on the second, fourth, sixth, eighth, and tenth 50-second segment of the 500 seconds. Thus, when the house light was not present, the stimulus complex was an S-delta. During the periods when the house light was on, there was an accelerated rate of responding. During the S-delta periods, the responding was suppressed compared to baseline. One interesting finding of these studies (Dews, 1962; Farmer and Schoenfeld, 1966) is that normal response patterns are not disrupted by interpolated periods of S-delta.

Dews followed this study with a series of experiments summarized in 1970. The fact that interpolated periods of S-delta did not disrupt FI response patterning (Dews, 1962, 1965a, 1956b, 1966a, 1966b) led to the conclusion that deviations of the third order (i.e., the scallop pattern of responding within each interval) are not the result of some complex chaining of behavior nor is it the result of some sort of behavioral mediation. If these factors were involved in the control of FI responding, then the disruption of the chain or the mediation by the S-delta would necessarily disrupt the overall pattern. Dews (1970) preferred the interpretation of FI responding which emphasizes the stereotypic effect of reinforcement.

While the FI schedule of reinforcement only requires a single response, many more usually occur and each one of these responses is followed by the reinforcer presentation. The difference, of course, is in the delays between each response and the reinforcer. The more temporally distant a response is from the reinforcer, the less it is strengthened. Such a pattern of strengthening would lead one to expect the scalloped pattern of responding that typifies FI responding. Thus Dews (1970) concluded: "All the responses in the fixed interval are followed by the reinforcer, so they should all be considered reinforced responses but differently strengthened because of delays of reinforcement of different lengths" (Dews, 1970, p. 47).

However, there are some data that weaken the "delay of reinforcement" hypothesis of Dews. Dews (1969) added a one second delay of reinforcement to an FI 3-min schedule of reinforcement; responding during the delay which was unsignalled had no scheduled consequences. The mean delay obtained with this procedure was approximately 0.25 seconds. Even with such a short delay of reinforcement, the response rate was cut in half compared to the baseline. These data indicate that the effective temporal range of a reinforcer may be far less than the duration normally found in FI schedules. It also points out the importance of a zero delay of reinforcement for the terminal response in the interval.

The importance of contiguity of responses and reinforcers has been demonstrated in other studies. Under FI schedules a single response is required after some time interval has passed. A similar

requirement can be arranged which does not guarantee temporal contiguity as does the standard FI schedule. A conjunctive fixed-time \underline{t} fixed ratio 1 schedule (Conj FT \underline{t} FR 1) requires that a single response be emitted and that a fixed amount of time has elapsed before the reinforcer is presented. Under this arrangement the response can occur at any time during the interval or after as in the FI schedule. If the response occurs before \underline{t} has elapsed, the reinforcer is presented immediately at time \underline{t} , thus contiguity between the responses and reinforcers would be strictly coincidental. Any differences found between an FI \underline{t} maintained performance and a Conj FT \underline{t} FR 1 maintained performance would presumably reflect the influence of contiguity of responses and reinforcers.

Shull (1970) compared the two procedures with minimum interreinforcer times of 60 and 300 seconds. The performance under the FI conditions was typical of FI behavior as described above. However, the performance under the Conj FT \underline{t} FR 1 consisted of a pause after the reinforcer presentation followed by responding, followed in turn by another pause. The duration of the post-reinforcement pause was not affected by the requirement or lack of a requirement of a response after the time \underline{t} had elapsed. However, the response rate was considerably lowered when the schedule did not guarantee contiguity between responding and reinforcement. Therefore, while the pause at the beginning of the interval may be independent of the response requirement, the large number of responses and the scalloped pattern of responding that typifies the FI pattern are at least partly the result of contiguity of the single required response with the delivery of the reinforcer.

Reinforcer magnitude is another variable that has a stereotypic effect on responding under FI schedules; however, the exact nature of this effect is not clearly known. Of the four studies done on this topic, three (Meltzer and Brahlek, 1968, 1970; and Stebbins, Mead, and Martin, 1959) have dealt with the stereotypic effects using different procedures and yielding somewhat different conclusions. (The fourth study by Staddon in 1970 will be discussed under dynamic effects.)

Stebbins, et al. (1959), using rats varied sucrose concentration across four conditions under an FI 2-min schedule. They found that response rate increased with increasing concentrations of sucrose (5, 12.7, 32, and 50 per cent solutions). When they plotted the percentage of total responses that occurred in each successive fifth of the interval, they found that when concentration was increased from 5 to 32 per cent there was an increase on the percentage of responses occurring in the earlier portion of the interval and a decrease in the percentage of responses occurring in the later portions of the interval. That is, there was an increase in overall response rate when concentration was increased and there was a decrease in the extent the response rate accelerated during the interval (i.e., less scalloping) when the concentration of sucrose was increased.

Meltzer and Brahlek (1968) conducted their experiment with rats under an FI 3-min schedule using a between-groups design. One group received three 45 mg food pellets and the other group received one 45 mg food pellet at the completion of the interval. They found the typical FI acceleration in response rates for both groups. While the three-pellet group responded more frequently than the one-pellet group,

the difference was not significant. However, there was a significant interaction between response rate in successive quarters of the interval and reinforcer magnitude. The interaction was due to a significantly higher response rate in the last quarter of the interval for the three-pellet group. When they compared the two groups on the basis of percentage of responses that occurred in each successive quarter, there was no difference. This lack of difference in the patterning measure contradicted the findings of Stebbins, et al., (1959).

Meltzer and Brahlek (1970) attempted to resolve the differences in the two studies by using the same procedures with a within-subject design. Three-pellet sessions were alternated with one-pellet sessions for a total of fifty sessions. The type of session was correlated with a lit or darkened chamber. Under these conditions they found that the response rate was higher under the three-pellet condition during the last two quarters of the interval but not during the first two quarters. Again, they found no difference in the patterning throughout the interval in terms of the percentage of responses emitted in each successive quarter of the interval. Meltzer and Brahlek (1970) concluded that the differences were due either to the use of alternating sessions vs. blocked conditions or the use of number of pellets vs. sucrose concentration. Bolles (1975) summarized evidence that indicates that sucrose concentration may function more as a qualitative difference in reinforcers than a quantitative difference as would be the case with the number of pellets. It appears safe to conclude that response rate can be enhanced by increasing the magnitude of the reinforcer (at least up to some limit) and that patterning under FI schedules is not affected

very much, if any.

Zeiler (1977) in his review of the literature on FI responding concluded that patterning found under an FI schedule is controlled by the relative position in the interval (i.e., the percentage of the interval that has elapsed). For example, Dews (1970) reported some data that showed response rate relative to the terminal rate as a function of the percentage of the interval that had elapsed for FI 30, FI 300 and FI 3000 sec. These three curves were essentially identical which indicates that the pattern of the scallop is a function of relative position in the interval. However, it is still not clear exactly what stimuli correlated with the passage of time control this patterning.

Hypothetically, there are three ways that an organism can "mark time": exteroception (e.g., a clock), proprioception (e.g., amount of behavior), and interoception (an "inner clock"). Exteroceptive stimuli, such as clocks mentioned above, have been shown to exert powerful stimulus control over behavior under a variety of conditions. Proprioceptive stimuli have been observed to exert some control over behavior when it is required that a certain amount of time must pass between responses (interresponse time $> \underline{t}$ schedule, or $IRT > \underline{t}$) (Laties, Weiss, Clark, and Reynolds, 1965; Laties, Weiss, and Weiss, 1969). The existence of an inner clock (interoceptive stimuli) has not yet been clearly demonstrated. Dimond (1964) summarized the view of the inner clock as follows:

It is supposed that the duration of stimuli and the intervals between them are compared with an internal standard. Such a standard could be represented by the steady functioning of some mechanism of the body. This role had been attributed to many mechanisms which function in a rhythmic manner, from the heart to the metabolic processes of the cells themselves (p 348).

Since in the present context it is probably a methodological impossibility to eliminate all exteroceptive and proprioceptive stimuli from an experimental situation, the existence of the "inner clock" may never be demonstrated.

Dynamic Changes of Behavior Under Fixed-Interval Schedules

The dynamic changes of behavior under a schedule of reinforcement are the result of the interaction between behavior and the direct and indirect variables operating under the particular schedule. Second-order deviations in responding under an FI schedule are considered to reflect a dynamic effect of the direct and indirect variables that operate under that procedure. Second-order deviations are the fluctuations in responding that occur from one interval to the next.

As mentioned previously, even though the fixed-interval schedule requires only a single response, many more responses typically occur. As a consequence, response number may operate as an indirect variable. The effect of response number under FI schedules has not been extensively explored but some interesting data are available.

Dews (1970) presented some data on second-order effects on a single subject under FI 180 seconds. These data were the number of responses in each interval for 200 consecutive intervals. Under these conditions the subject's responses per interval varied from less than 50 to more than 900 (sic), with the variability remaining approximately constant throughout the session. These data are shown in Fig. 2. In order to check for second-order effects, Dews (1970) then constructed a

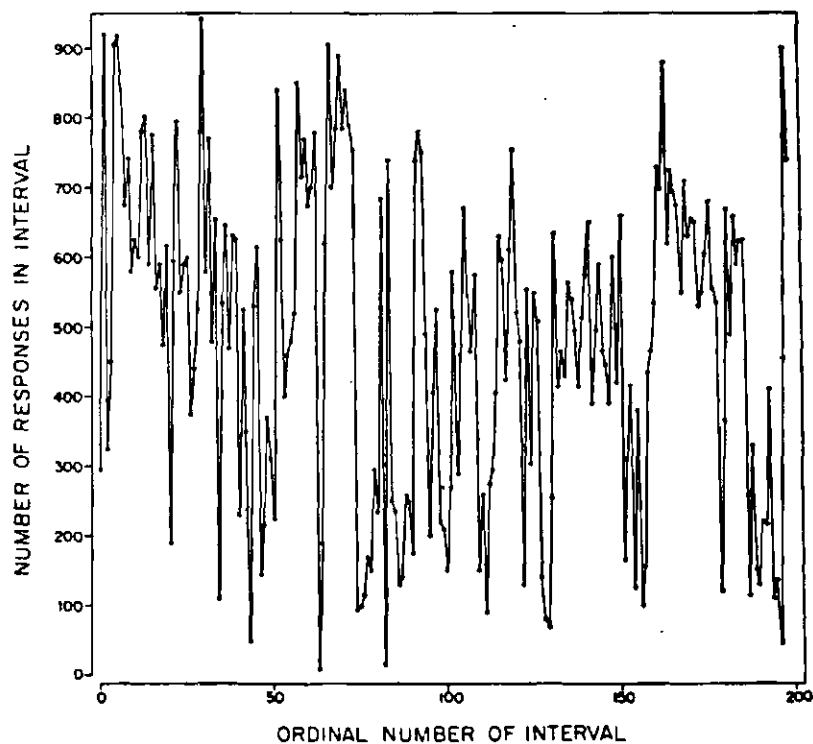


Figure 2. Response Number for 200 Consecutive Intervals
(From Dews, 1970)

sequence of histograms that showed the distribution of responses per interval as a function of the number of responses in the preceding interval. These histograms (Fig. 3) show that there is a tendency for intervals containing few responses to be followed by intervals containing few responses and for intervals containing many responses to be followed by intervals containing many responses. Thus, these data seem clearly to contradict the notion of second-order deviations as described by Skinner (1938).

Dews (1970) then performed a different sort of analysis on the data shown in Fig. 2. This time he looked at local minima (points that were lower than both the preceding and succeeding points) without regard to absolute number of responses. When he calculated the expected number of intervals between such local minima (sequence length), he found that there were more short sequences than should be expected. Dews (1970) concluded that alternation was occurring, but the effect was small.

Shull (1971) reported another study which looked at the second-order effects quantitatively. In his first experiment, two pigeons responded under FI schedules; one pigeon was tested under FI 60 sec, then FI 30 sec, then FI 300 sec, while the second pigeon was tested under FI 60 sec and FI 300 sec. From these data Shull calculated lag-1 autocorrelations for pause duration; i.e., the correlation of the pause duration for interval n with interval $n+1$. The autocorrelations for each bird for each of the FI parameters are shown in Fig. 4. The lag-1 autocorrelations under FI 300 sec were negative for both pigeons. but the results were inconsistent at the shorter FI values. The second experiment was designed by Shull to determine if the pause in interval

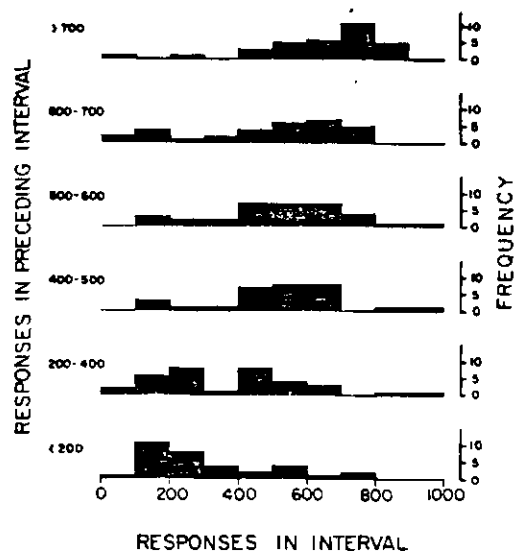


Figure 3. Frequency Distribution for Response Number for 200 Consecutive Intervals (From Dews, 1970)

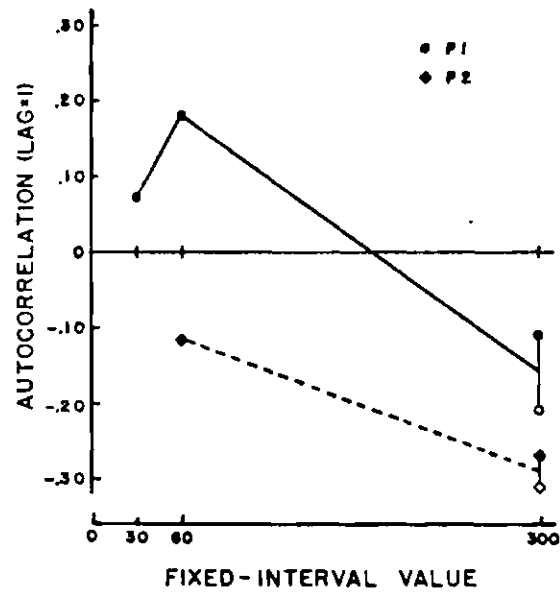


Figure 4. Lag 1 Autocorrelations for Three FI Values
(From Shull, 1971)

$n+1$ was a function of the work period in interval n (the work period being the time between the first occurrence of a response in the interval and the presentation of the reinforcer).

The duration of the work period was controlled by the use of a conjunctive schedule arrangement (i.e., two or more schedule components must be completed prior to the presentation of the reinforcer). Under this schedule the first response after 300 sec was reinforced if at least t seconds had elapsed since the first response in that interval; i.e., Conj (FI 300-sec Tand FR 1 FI t). The values of t of 60, 120, and 180 sec set the minimum work period for each interval. Since this conjunctive arrangement altered the interreinforcer interval, another condition was used to provide the same interreinforcer intervals without restricting the work period. This schedule arrangement was a VI t . Since this still left the work period uncontrolled, a Tand FR 1 VI t was also used. Finally, a Tand FR 1 FI t was used where t was the mean of the intervals used in the Tand FR 1 VI t . The mean pause times and the autocorrelations for these conditions are shown in Fig. 5. It can be seen in the figure that the restriction of the work period (imposing a minimum) eliminated the negative lag-1 autocorrelation. However, it is not clear that the duration of the work period per se is the controlling variable for pause duration in the next interval because response number should also be highly correlated with work time. Thus, by requiring a work period of a certain duration, the likelihood of higher response number is also increased. Shull did not give any data on response number.

While the literature does not contain a clear quantitative

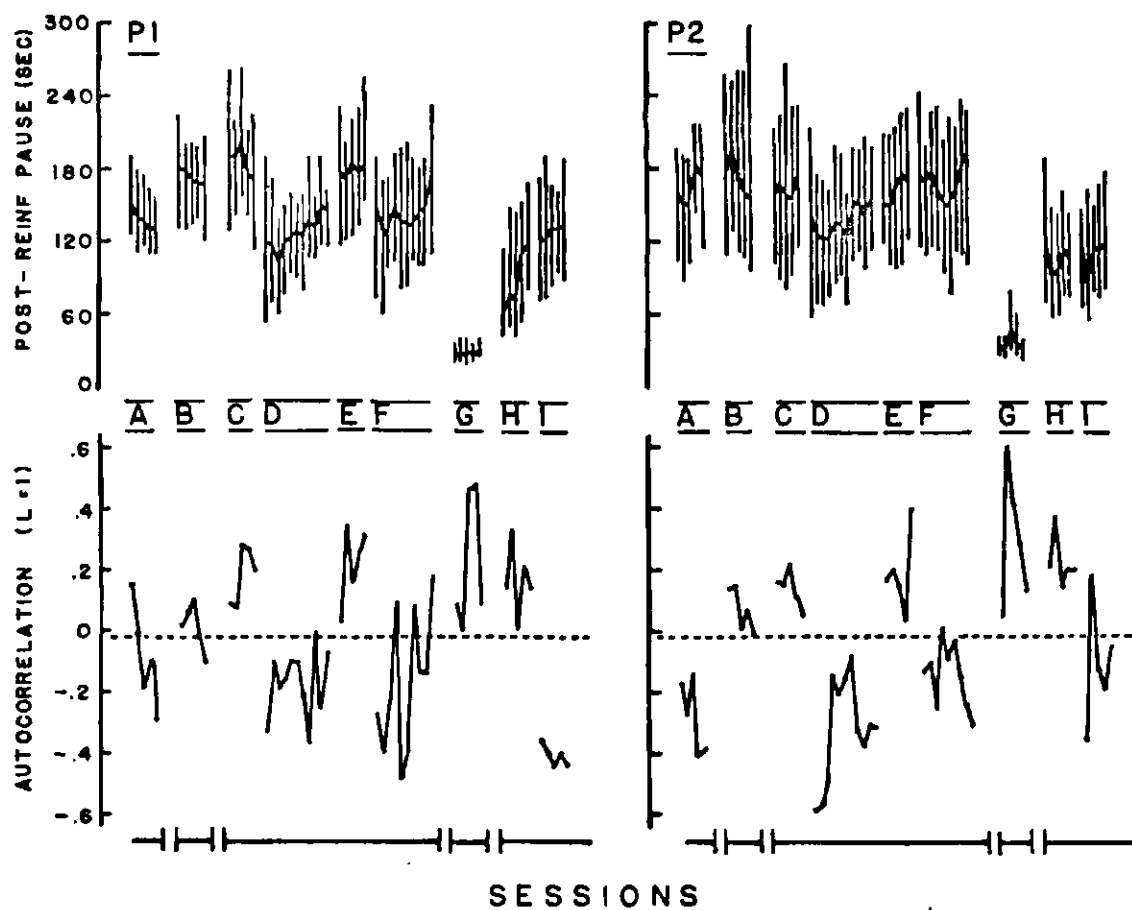


Figure 5. Lag 1 Autocorrelations and Post-Reinforcement Pause
(From Shull, 1971)

demonstration of second-order effects under FI schedules based on response number, the concept has been used in theoretical explanations of FI-engendered behavior. Zeiler (1977) described the regenerative properties of FI schedules. When behavior weakens, very few responses will be emitted, leading to a small value of responses per reinforcer. When there are few responses per reinforcer, behavior should be strengthened. When behavior is very strong, many responses will occur leading to a large value of responses per reinforcer. When responses per reinforcer has a high value, behavior will be weakened. The best experimental support for the regenerative properties of the indirect variable responses per reinforcer comes from a study performed by Herrnstein and Morse (1958). Where Shull (1971) used a conjunctive schedule arrangement to set a minimum work period under an FI schedule, Herrnstein and Morse (1958) used the conjunctive schedule to set a minimum for the number of responses per interval.

After establishing a baseline of responding under an FI 15 min schedule of reinforcement, Herrnstein and Morse (1958) changed the schedule to Conj FI 15 FR n (i.e., the first occurrence of a response after 15 minutes will produce the reinforcer if at least n-1 responses had already been emitted, otherwise the completion of a total of n responses after the 15 minutes had elapsed will produce the reinforcer). The values of the FR were 10, 40, 120, and 240 (10 was used only for one of the two pigeons). The response rates that resulted from the different values of the FR are shown in Fig. 6. The size of the response requirement had a clear effect of decreasing the response rate even though the requirement might have been far less than the number of

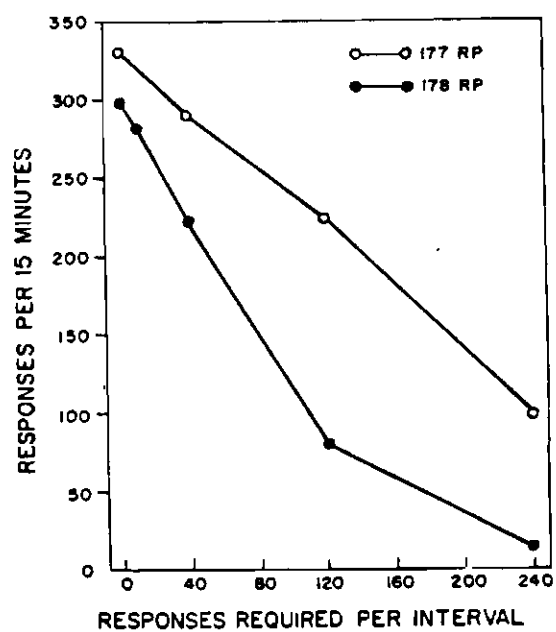


Figure 6. Overall Response Rate and FR Requirement (From Herrnstein and Morse, 1958)

responses that were usually emitted under simple FI 15 min by these subjects.

Herrnstein and Morse (1958) interpreted their results in terms of eliminating the regenerative properties of the FI schedule. When behavior weakens under Conj FI t FR n schedule, fewer than n responses will not result in the presentation of the reinforcer regardless of how much time has passed. Thus if behavior has weakened to the point that the organism makes contact with the FR requirement, the regenerative strengthening will not occur to the extent that it would under a simple FI t . Thus an important reason for the large amount of behavior that can be maintained under an FI schedule is that little behavior is required.

Herrnstein and Morse (1958) studied the influence of the indirect variable of responses per reinforcer by changing it to a direct variable. In doing so they also changed the direct variable of interreinforcer interval. If the subject had not completed the FR requirement when the interval elapsed, then the direct variable, interreinforcer interval, became an indirect variable as under the normal FR schedule. Figure 7 shows the mean interreinforcer interval did indeed increase with increasing ratio requirements.

If responses per reinforcer can function as an effective indirect variable under FI schedules, then there are other manipulations that can be made to demonstrate its effect. One such manipulation involves the use of added stimuli as in the case of the clock discussed above. In this case the stimuli change as a function of the number of responses that are emitted during the interval. This added stimulus arrangement is called a "counter".

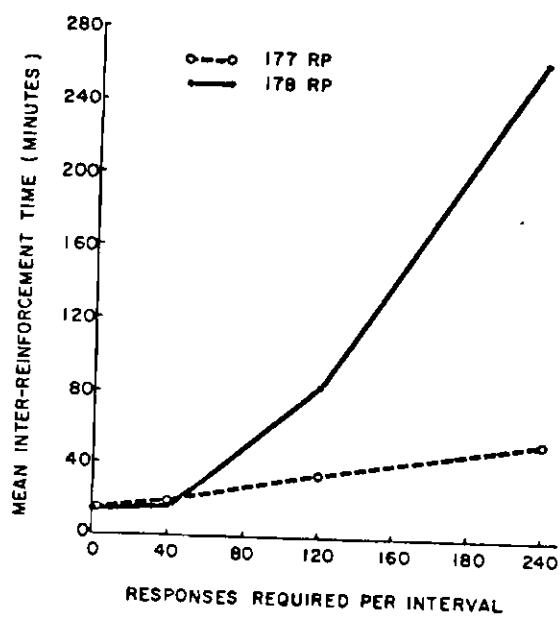


Figure 7. Inter-reinforcement Time and FR Requirement (From Herrnstein and Morse, 1958)

Ferster and Skinner (1957) did some preliminary work with counters under FI schedules. They used the same slit of light on the response key as used for the clock described above. In this case the slit grew larger with each response. The largest size was attained at approximately 600 responses. They tested three pigeons with this procedure, one each at FI 5, FI 10, and FI 20 min.

Before the counter was added the pigeon under FI 5 min exhibited "rough grain" (groups of responses with frequent short pauses). When the counter was added, the FI scalloped pattern developed. Control of responding by the slit was demonstrated by using the largest setting and then the smallest setting. With the counter at the optimal setting, a high response rate was maintained. At the least optimal setting, a very low rate of responding occurred with scalloping. While the counter was in the normal operating mode, there was no prolonged pausing at the beginning of the interval and there was typical FI scalloping.

The pigeon under FI 10 + counter developed deeper scalloping than was exhibited under FI 10 alone. With the counter at the optimal setting, response rate was maintained at a high steady rate. The subject under the FI 20 + counter began with a baseline of a low steady response rate. When the counter was initiated, scalloped responding developed. Again, the maximal setting of the counter controlled a high rate of responding.

Ferster and Skinner (1957) concluded that two things resulted from the counter. First, the production of count is reinforcing. The consequence of each response under this arrangement was the alteration of the size of the stimulus. Furthermore, the initial setting of the

counter is rarely present when the response is reinforced. Thus, "this negative control evidently cancels the reinforcing effect of the production of count" (Ferster and Skinner, 1957, p. 304). They also noted from the cumulative records that when reinforcement did occur at a low setting of the counter, the pause was shorter on the next interval.

Another dynamic effect arises from the reinforcer magnitude. Staddon (1970) found a relationship between response rate and reinforcer magnitude and between post-reinforcement pause and reinforcer magnitude. After establishing a baseline under FI 1-min schedule terminating in 3.3 sec access to grain, the grain durations were randomly selected from 1.3, 2.4, 4.5, 5.7, and 9.0 sec. It was found that pause time increased with increasing durations of the preceding reinforcer. Also, the overall and running rates of responding decreased with increasing durations of the preceding reinforcer. Thus, a variable operating supposedly in one interval has an effect in the following interval.

CHAPTER II

STATEMENT OF THE PROBLEM

As described in Chapter I, fixed-interval schedules engender characteristic patterns of responding. Two aspects of FI-engendered behavior are to be studied in this experiment. First, what is the role of the indirect variable of responses per reinforcer? Second, what is the nature of the control exerted by a "counter" (added stimulus)?

The interval-to-interval fluctuation in number of responses (second-order deviations) that has been described by several authors (Ferster and Skinner, 1957; Skinner, 1938; Zeiler, 1977) has been attributed to the dynamic effect of responses per reinforcer, primarily due to the data from Herrnstein and Morse (1958) and Dews (1970). However, the interpretation of this phenomenon has not been very clear because little has been done to indicate the magnitude of the phenomenon. Dews (1970), using the data from one pigeon gathered in one session, indicated that there was a slight tendency for alternation of high and low response number intervals. Prior to the Dews chapter, the evidence for the second-order deviations has come from observation of cumulative records.

The experimental evidence indicating the influence of responses per reinforcer comes from Herrnstein and Morse (1958). They studied the effect of this indirect variable by making it a direct variable, i.e., by requiring a fixed number of responses. The Conj FI t FR n arrangement produced orderly data; however, it is not clear that the

effect of responses per reinforcer was studied directly by this method. In changing from FI t to Conj FI t FR n schedule of reinforcement, the direct variable of minimum interreinforcer interval was also changed. Thus, in those intervals in which at least $n-1$ responses had not been emitted before the time t had elapsed, the direct variable (minimum interreinforcer interval) became an indirect variable (as it normally is under an FR schedule).

Two techniques will be used to assess the role of responses per reinforcer in FI-engendered responding. If the second-order fluctuations in responding are partially due to the influence of the responses per reinforcer, then the magnitude of the second-order fluctuations should be decreased or minimized by holding responses per reinforcer at an approximately constant value. This variable could be held at a nearly constant value by altering the reinforcement cycle at the end of the interval. One grain presentation (i.e., access to grain) could be made for every n responses emitted during the interval. Thus, the number of responses per reinforcer would have a value of approximately n (as in the case of an FR n schedule). This procedure allowed any number of responses to occur during the interval as is normally found under FI schedules; however, more reinforcers will be presented at the end of the interval if a larger number of responses are emitted during the interval.

While this procedure should minimize the influence of responses per reinforcer, it introduces another variable into the normal FI arrangement. Staddon (1970) found an orderly decrease in response rate and an increase in pause time following increased magnitudes of

reinforcers. While the number of grain presentations is not exactly the same as durations of grain presentation, similar results may obtain. Thus, intervals with high response count would terminate with high reinforcer frequencies compared to intervals with low response count. These high reinforcer frequencies should decrease responding in the following interval if Staddon's results hold.

A detailed analysis of the number of responses in interval n given the number of responses in interval $n-1$ should clarify the role of the three potential variables: response number, responses per reinforcer, and reinforcer frequency. In addition, any changes in the pattern of responding within intervals due to this procedure would be detected from response rate and quarter-life data (quarter life is a measure of curvature in the FI scallop; specifically, quarter life is the mean percentage of the interval that has elapsed when one fourth of the total number of responses has been emitted). Changes in response rate and quarter life may result from increased mean reinforcer magnitude and from differentially reinforcing high response counts. While it is not clear that making a higher reinforcer frequency depend upon a high response frequency will alter responding toward a higher count, there is some theorizing in the literature that a correlation between behavior and reinforcement could have powerful effects and that contiguity is not necessary (Baum, 1973; Rachlin, 1976). Thus, there might be a stereotypic effect of producing higher response count under this procedure.

Another technique for assessing the role of responses per reinforcer under FI schedules is to use a "counter" (added stimuli that

change as a function of the number of responses emitted in the interval). If response number does indeed control behavior either within an interval (a behavioral "clock"), across intervals (dynamic effects), or both, then the effects should be enhanced by providing a stronger stimulus than an "internal counter" that must be operating under the normal FI arrangement. If there is a tendency for alternation of high and low response-count intervals, then the counter should enhance the effect. Furthermore, if response count can function as a timing method under FI schedules, then this influence could be demonstrated by the use of the external counter with the sequence of stimuli altered. For example, if the stimulus normally associated with a high count is presented at the beginning of the interval, then the pause should be shortened since this stimulus is also normally associated with the end of the interval. This control by a counter has already been shown to be effective in controlling behavior within the interval (Ferster and Skinner, 1957), but the influence across intervals has not been well documented.

The influence of the external counter will also be assessed by comparing response rates in the presence of each of the stimuli with the rates that occur under FI without the stimuli. That is, how long does it take to complete the first n responses, the second n response, etc., under the two procedures? Any difference would presumably reflect a combined effect of the external counter operating as a "clock" indicating how much behavior has occurred since the previous reinforcer and the reinforcing effect of count production as proposed by Ferster and Skinner (1957). If reinforcement occurs very frequently in the

presence of the last stimulus of the counter (which indicates a high count), then that stimulus may acquire conditioned reinforcing properties due to the direct association with reinforcement. If this condition should obtain, then responding in the presence of the next to last stimulus may be maintained at a higher rate by the presentation of the last stimulus. Also, since there is no requirement on response number, reinforcement could occur in the presence of any of the stimuli that comprise the counter. Marr (1971) explored second-order schedules, the behavior engendered by the component schedule is treated as a unitary response which is then reinforced under another schedule. The completion of a component either results in a stimulus change or reinforcement. One of the arrangements used by Marr (1971) was a Seq FI \underline{T} (FI \underline{t}); under this arrangement the first FI \underline{t} completed after \underline{T} min since the onset of the interval was reinforced. The completion of each FI \underline{t} resulted in a stimulus change (there was a maximum of four stimuli since \underline{T} was always four times longer than \underline{t}). Responding was maintained in the presence of all four stimuli, even though only the completion of one component was required by the schedule. Also the response rate was frequently highest in the next to last stimulus, not the last one. The rates of responding were considerably lower in the presence of the first two stimuli, presumably for two reasons: the termination of the early components rarely resulted in the presentation of the reinforcer and the overall FI character of the schedule (i.e., initially low response rates followed by higher response rates) (Marr, 1971).

To clarify further the roles of response number and responses per reinforcer, another condition will be used in which reinforcer frequency

at the end of the interval will be correlated with response count during that interval and an external counter will be present. Under this arrangement the completion of the interval with a low response count would result in a single reinforcer being presented during the first stimulus of the counter. Completion of an interval with a high count would result in a high frequency of reinforcement in the presence of the last stimulus of the counter. Likewise, intermediate response counts would result in an intermediate number of reinforcements in the presence of intermediate stimuli of the counter. The presence of the counter under this condition should enhance the effects expected under the first condition in which there is to be a correlation between response rate and reinforcement frequency, however, without an external counter.

The final experimental manipulation will be to compare "clock" controlled behavior with "counter" controlled behavior under an FI schedule. As described above, clocks exert powerful control over the patterning and rate of responding maintained by FI schedules (Ferster and Skinner 1957; Laties and Weiss, 1975; Segal, 1962). Since the amount of behavior that has occurred since the onset of an interval may function as a crude clock, the counter arrangement may be considered as a clock. However, in this case the change in stimuli requires some amount of behavior, while the clock stimuli change independently of behavior. Furthermore, clocks have been arranged to be "perfect" indicators of time, while the "clock" function of the counter is very irregular since it depends upon behavior of the subject. To study the relative control exerted by the two methods (clock and counter), the temporal patterns of stimulus changes under the counter condition will

be presented to the subject independent of its behavior, i.e., as an irregular clock. A yoked-control procedure will be used: each subject will be exposed to a sequence of clock stimuli of the same durations which were generated by its own behavior pattern under the counter arrangement.

The differences in patterns and rates of responding under the two conditions should indicate the relative importance of the counter as a crude clock. Since the frequency of reinforcement in the presence of each stimuli will be the same under both conditions (due to yoked-control procedure), differences in the rates of responding in the presence of each of the stimuli should indicate possible conditioned reinforcing properties of the counter stimuli.

In addition to the above, an attempt will be made to improve the measurement techniques used to describe the second-order deviations. Dews (1970) graphically displayed the distribution of response counts for a given number of responses in the preceding interval (Fig 3). Dews (1970) also calculated the expected number of intervals between two successive local minima. These two measures by Dews are the only quantitative measures of second-order fluctuations in response number in the literature (Shull's (1971) data involved pause durations only). An autocorrelation analysis will be performed for each of the conditions for lags of 1, 2, 3, 4, and 5. If the second-order deviations are more than a laboratory fable, then at lag one the autocorrelations should be negative and the degree of this negative relationship would indicate how pronounced the "up-and-down" pattern is.

In summary, this research will explore the role of the number of

responses emitted under an FI schedule of reinforcement. The manipulations will involve holding the indirect variable of responses per reinforcer approximately constant and the use of a counter to enhance the effects of that variable. Finally, the control exerted by an external counter will be compared to the control found under the influence of an external clock by using a yoked-control procedure.

CHAPTER III

METHODS

Subjects

The subjects were four male White Carneaux pigeons (P8, P9, P289, and P70) maintained at approximately 80% of their free-feeding weights. Each of the subjects had previous experience in various operant conditioning experiments; all four subjects were most recently used in a second-order schedule experiment involving ratios and intervals. P289 has a more extensive history under second-order schedules.

Apparatus

A Grason-Stadler operant conditioning chamber was used in this experiment. The chamber contained one response key that required a minimum force of 0.12 N to operate, and, when operated, provided auditory feedback. A feeder that allowed 2.5 sec access to mixed grain was located below the key. The chamber was illuminated by a 6 watt white light except during blackouts. The response key could be transilluminated by different colors and stimulus patterns by 28 VDC lamps (number 1829). Masking noise was present throughout each session. The programming and recording of events was controlled by electro-mechanical devices in an adjacent room.

Procedure

Baseline performance under an FI 5 min schedule was established first. The first response on an amber-lit key after five minutes

initiated the reinforcement sequence. The reinforcement sequence began with the immediate offset of the key light. The feeder magazine was lit and grain presented 0.5 sec later. After 2.5 sec access to grain the chamber was darkened for one minute, after which the cycle restarted with the onset of the amber key light and houselight. Responding during the blackout had no scheduled consequences. Each session ended after the twentieth interval. This baseline condition remained in effect until quarter life and response rates stabilized. The criterion for stability was no detectable trends for at least five sessions.

In the first experimental condition, a positive correlation between response rate and reinforcement frequency was imposed. There was one grain presentation per 50 responses for P8, P70, P289 and one grain presentation per 100 responses for P9. The ratio of 50 responses per reinforcer was selected on the basis of baseline performance so that satiation was not likely to occur in a session of twenty intervals. The reinforcement sequence in this condition began with the immediate offset of the key light for the first response after 5 min. The feeder was lit 0.5 sec later with the simultaneous presentation of grain. If a sufficient number of responses had occurred in that interval, a second grain presentation occurred 0.5 sec after the first had terminated. This was repeated until there had been one grain presentation for every n responses in that interval. After the last grain presentation the chamber was darkened for one minute, after which the cycle was repeated. This condition remained in effect until quarter life and response rates had stabilized.

The next condition was a return to baseline. The procedures were

identical to the initial baseline.

The next experimental condition had the added stimuli that changed as a function of the number of responses emitted in the interval. Four different key colors and one symbol comprised this counter; they were, in order, amber, green, white, red, and square (white on black background). The counter changed every n responses where n was selected on the basis of the preceding baseline condition so that if the mean number of responses were emitted, the reinforcer would be presented during the fifth (and last) stimulus of the counter. The values of n were 25 for P8, P70, and P289, and 50 for P9. This condition remained in effect until quarter life, overall response rate, and response rate in the presence of each of the stimuli had stabilized. During one session after responding had stabilized, the sequence of stimuli was reversed to determine the extent of stimulus control for each of the stimuli.

The next condition was a return to baseline with the procedures being identical to the first baseline.

The next experimental condition was a combination of the first two conditions; i.e., responses per reinforcer was held approximately constant and there was a counter. Under this arrangement, if the interval were terminated in the presence of the first stimulus (amber), one grain presentation followed; if the interval were terminated in the presence of the second stimulus (green), two grain presentations followed; etc. Since there were only five stimuli in the counter, the maximum number of grain presentations was five. This condition remained in effect until quarter life, overall response rate, and response rate

in the presence of each stimulus were stable.

The next condition was the reinstatement of the straight counter as in the second experimental condition. The data obtained in this condition was used in a yoked-control procedure for the next experimental condition. The duration of each stimulus for four sessions for each pigeon was recorded. These durations were then used in a clock arrangement. The same five stimuli as in the counter were presented in the same order as in the counter for the durations as measured in the previous condition. Since the last condition was a clock arrangement, the stimuli changed independently of behavior. The four yoked-control sessions were presented to the subjects in a random order an equal number of times until responding had stabilized.

Table 1 summarizes the sequence of conditions and the number of sessions in each condition.

Table 1. Experimental Conditions and
Number of Sessions Per Condition

I	FI 5 minutes	
	P8	40
	P9	39
	P70	42
	P289	42
II	FI 5 minutes:	correlated reinforcement rate
	P8	56
	P9	51
	P70	52
	P289	56
III	FI 5 minutes	
	P8	17
	P9	16
	P70	17
	P289	17
IV	FI 5 minutes:	counter
	P8	39
	P9	37
	P70	39
	P289	41
V	FI 5 minutes	
	P8	21
	P9	20
	P70	20
	P289	23
VI	FI 5 minutes:	correlated reinforcement rate and counter
	P8	52
	P9	57
	P70	60
	P289	60
VII	FI 5 minutes:	counter
	P8	13
	P9	14
	P70	13
	P289	12
VIII	FI 5 minutes:	clock yoked to counter of VII
	P8	19
	P9	17
	P70	18
	P289	22

CHAPTER IV

RESULTS

The results to be described in detail below showed that the effects of the correlated reinforcement rate (condition II), the counter (condition IV), and the combination of the two (condition VI) were not consistent. However, the yoked-control procedure (conditions VII and VIII) showed that the added stimuli were effective in maintaining some control of behavior. Due to the nature of the results, the data will be presented across conditions. The means represent the last five sessions (four sessions for conditions VII and VIII) unless otherwise specified.

Response Rate and Quarter Life

Overall response rate and quarter life are two of the more common measures of FI performance. Overall response rate is obtained from the number of responses in a session divided by the session duration. By itself, overall response rate does not effectively describe FI performance. Quarter life is the percentage of the interval that has elapsed when on the average one fourth of the total responses has been emitted. These two measures together reflect the stereotypic performance under a FI schedule.

Overall response rate means and ranges across the eight conditions are plotted for each of the four subjects in Fig. 8. The only apparent reliable effects were in the change from condition VII to condition VIII (counter to clock-yoke). P289 showed a decrease and P9 showed an

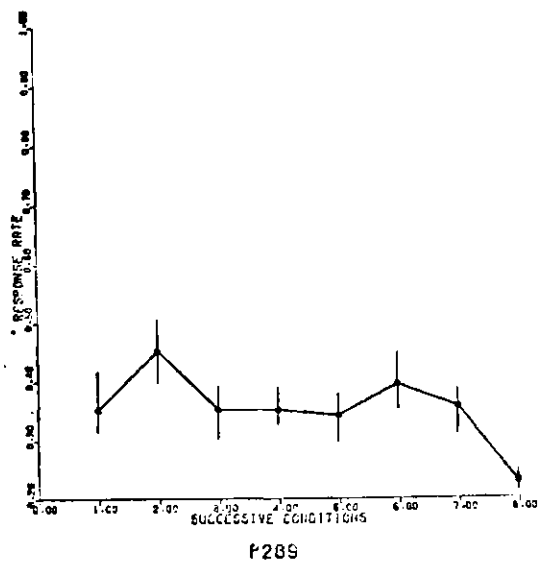
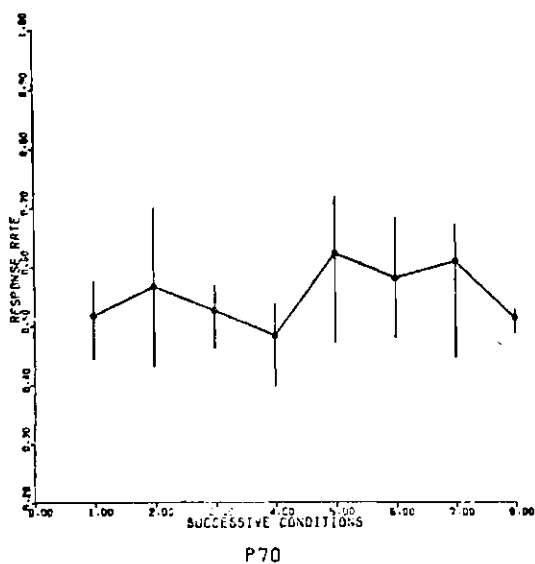
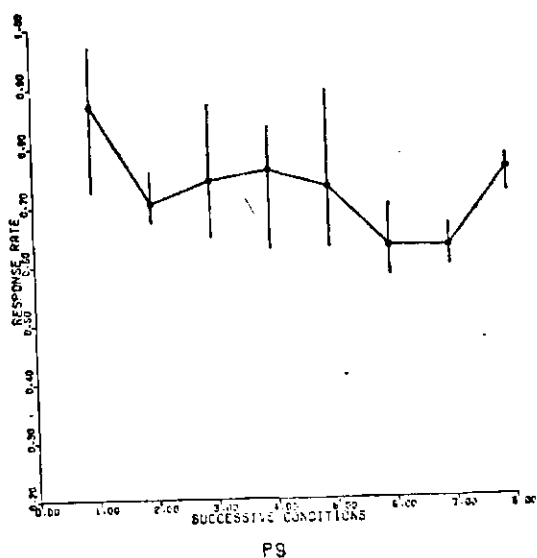
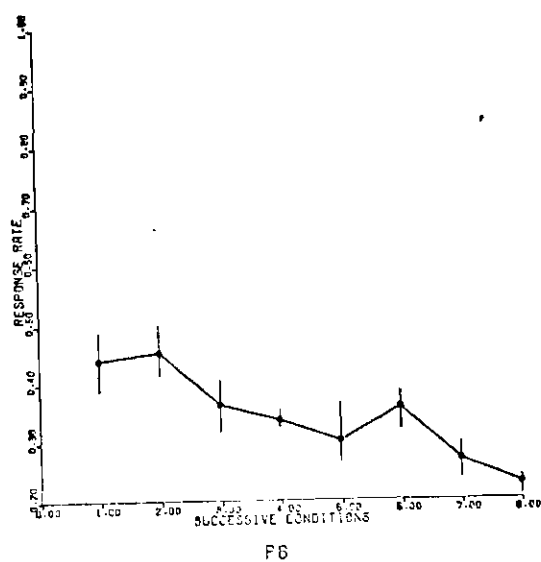


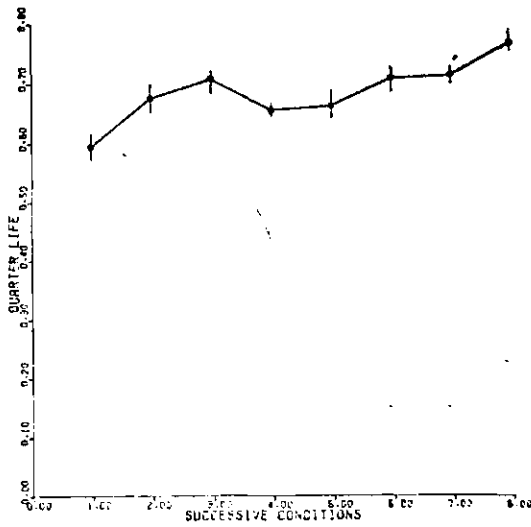
Figure 8. Overall Response Rate over Conditions

increase in rate. P8 and P70 showed no reliable effect in the transition from VII to VIII. Thus, the effects of the experimental manipulations on overall response rate were minimal and inconsistent.

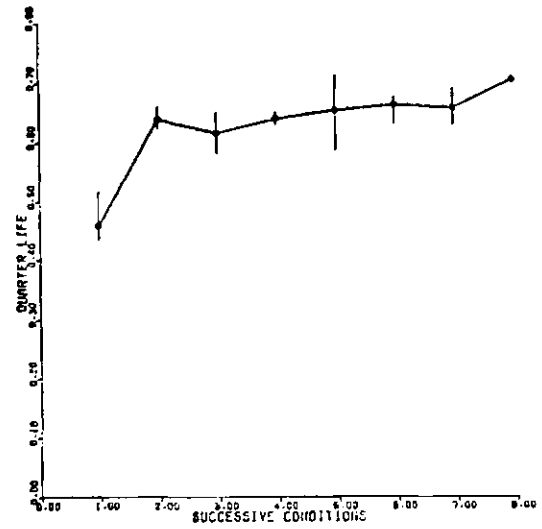
Quarter life data did show several effects of the experimental manipulations. These data with the ranges are plotted in Fig. 9 across all eight conditions for the four pigeons. The most striking feature of Fig. 9 is the increase in quarterlife after the first condition (P289 did not show the increase until condition III). Returning to baseline in conditions III and V did not result in recovering the original low quarter-life values. The quarter life also increased with the transition from counter to clock-yoke (condition VII and VIII) for P8, P9, and P289. The effect was not as marked with P70. These effects can also be seen in a plot of response rate as a function of time into the interval as shown for all four pigeons in Fig. 10.

Autocorrelations

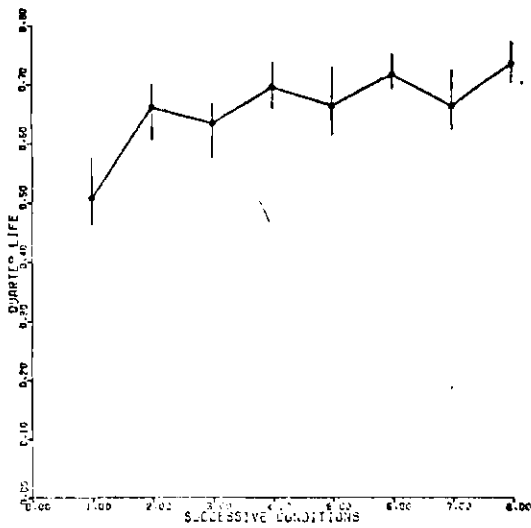
Autocorrelation functions with lags of 1, 2, 3, 4, and 5 were calculated on response number for each subject under each condition. Lag 1 autocorrelations are plotted in Fig. 11 with 90 per cent confidence intervals across the eight conditions. As was the case with overall response rate, there was no reliable effect from any condition that was consistent for all four subjects. The correlated reinforcement rate (condition II) produced a decrease in the magnitude of the lag 1 autocorrelation for P70; however, the same condition produced an increase for P289. P8 and P9 showed no effect in the transition from condition I to II. P8 and P9 showed an increase in the magnitude of the



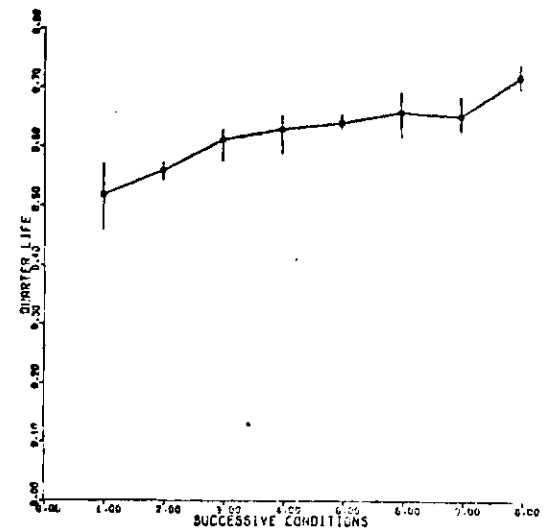
P8



P9



P70



P289

Figure 9. Quarter Life over Conditions

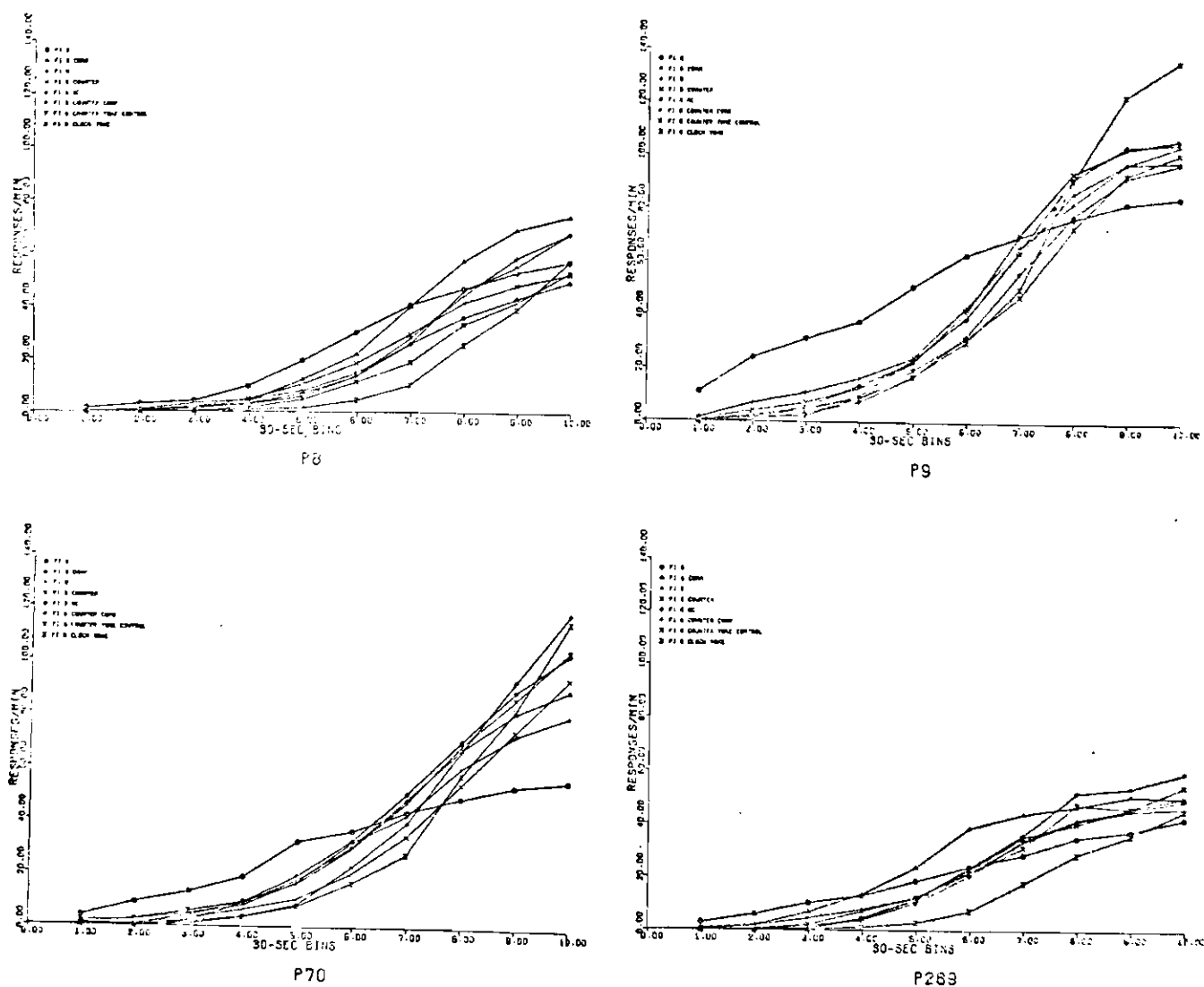
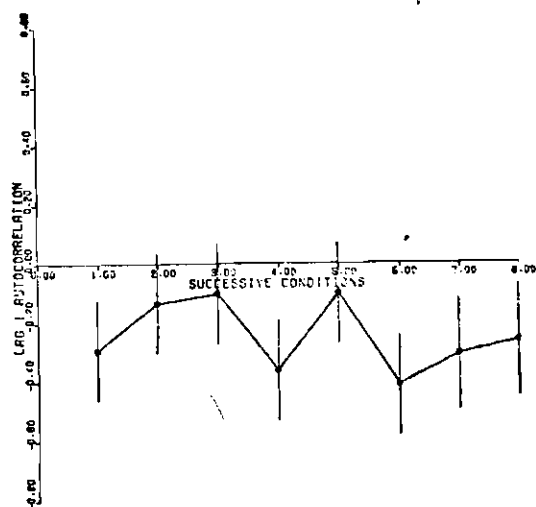
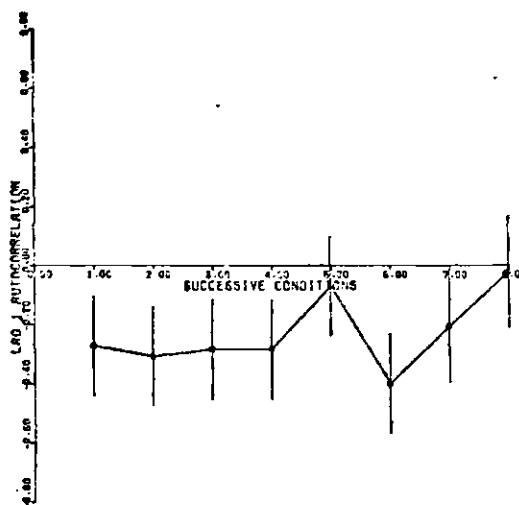


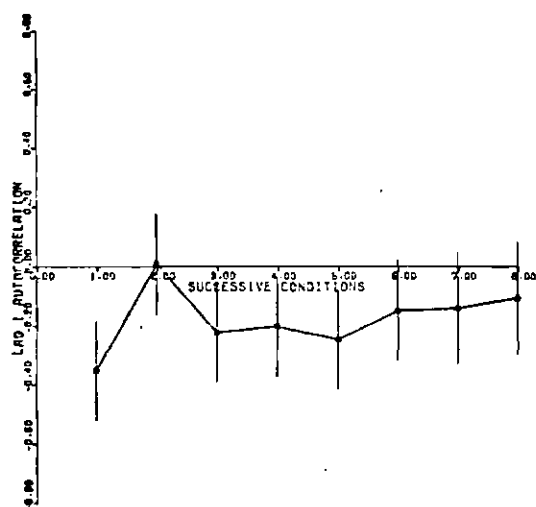
Figure 10. Response Rate Per FI Bin over Conditions



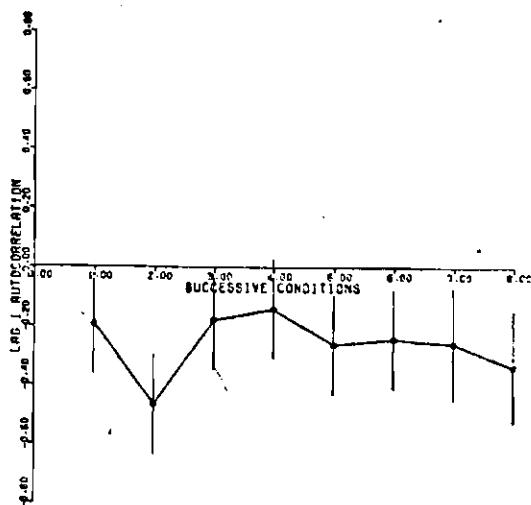
P8



P9



P70



P289

Figure 11. Lag 1 Autocorrelation over Conditions

autocorrelation in the transition from condition V to VI; however, P70 and P289 showed no effect.

The data in Fig. 11 are not only quite consistent across the eight conditions, but also the confidence intervals indicate that lag 1 autocorrelations are typically less than zero. Of the 32 lag 1 autocorrelations shown, only one was positive (P70 under condition II) and only 10 included 0.0 in the 90% confidence interval. While these data indicate a consistent negative lag 1 autocorrelation, the magnitude is quite small. The proportion of variability in response number accounted for by the response number in the previous interval is between 0 and 15 per cent.

The autocorrelations with the higher lags (2 through 5) showed neither consistency (i.e., mostly positive or mostly negative) nor were they reliably different from zero.

An analysis of the number of responses in interval $n+1$ for the number of responses in interval n revealed no information beyond that found in the lag 1 autocorrelations.

Response Rates with Added Stimuli

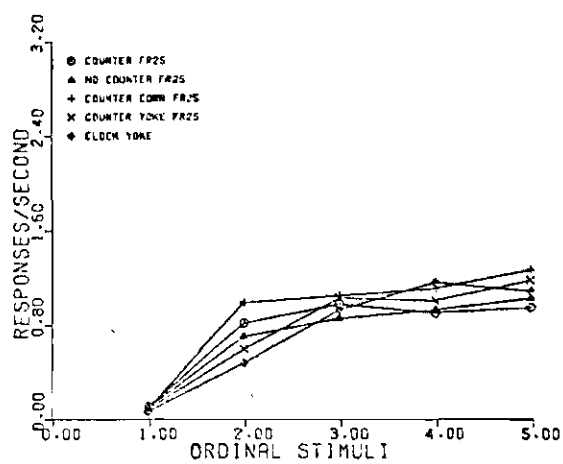
Under conditions IV, VI, VII, and VIII stimuli were added to the normal FI arrangement. Under condition IV and VII the stimuli changed as a function of the number of responses emitted during the interval, i.e., a counter. Under condition VI each successive stimulus of the counter was also associated with a higher frequency of reinforcement. Under condition VIII, the clock-yoke condition, the duration of each stimulus was determined by the pigeon's own behavior in condition VII.

In addition, rates were calculated for condition V as if the stimuli were added as with condition IV and VII.

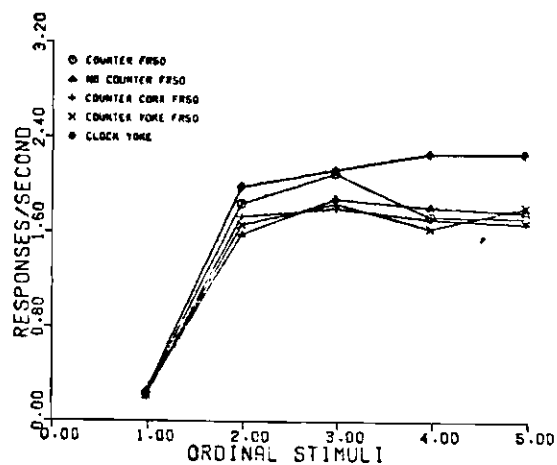
The response rates in the presence of each stimulus for the four subjects are plotted in Fig. 12. The effects of changing conditions were not consistent among the four subjects. P289 and P70 showed a decrease in response rate during the first three stimuli of the clock-yoke condition (VIII). P8 showed no reliable change across conditions, while P9 increased response rate in the later stimuli.

Under conditions IV, VI, and VIII the sequence of stimuli were reversed to determine if indeed they exerted any control over behavior. The effect of the reversed counter for four intervals during condition IV is shown in Fig. 13. P8 maintained a relatively stable rate of responding in the presence of the five stimuli; there was a higher rate in the first stimulus (shorter initial pause) and a lower rate in the last four. P70 showed a decrease in response rate in the last two stimuli of the reversed counter. P289 showed a slight increase in rate for the first stimulus. P9 only showed an effect for the third stimulus. Thus, while the results of reversing the stimuli for the counter for condition IV are not consistent across the four subjects, the stimuli had gained some degree of control over behavior.

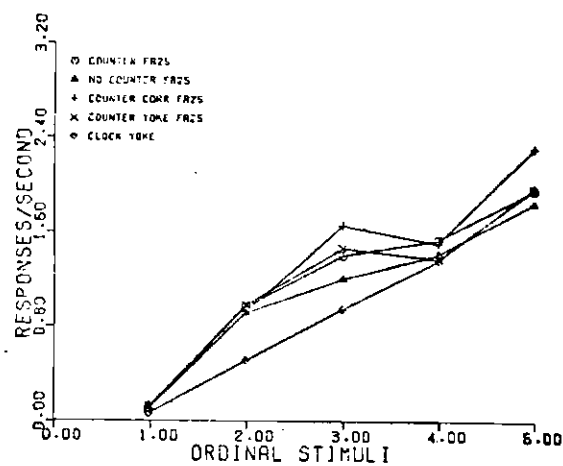
The effects of reversing the stimuli for conditions VI and VIII, four intervals and five intervals, respectively, (counter with correlation and clock-yoke) are shown in Figs. 14 and 15. With the exception of P9 under the counter plus correlation stimulus reversal, the effects were quite marked, showing that the stimuli did exert some control over behavior.



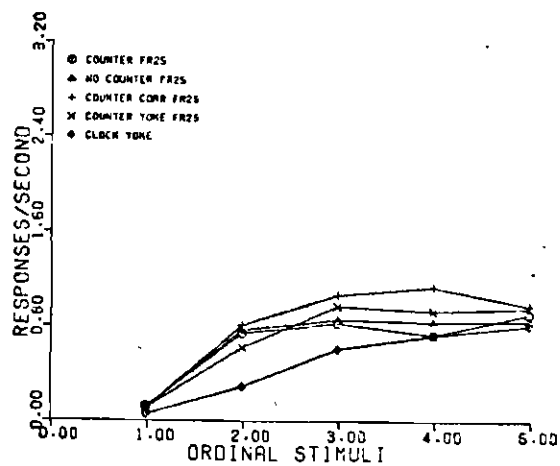
P8



P9

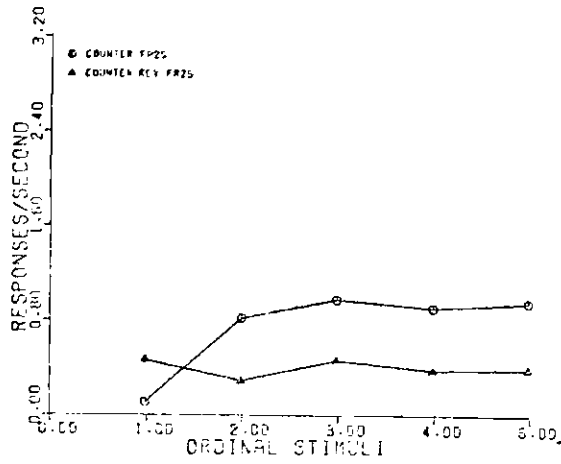


P70

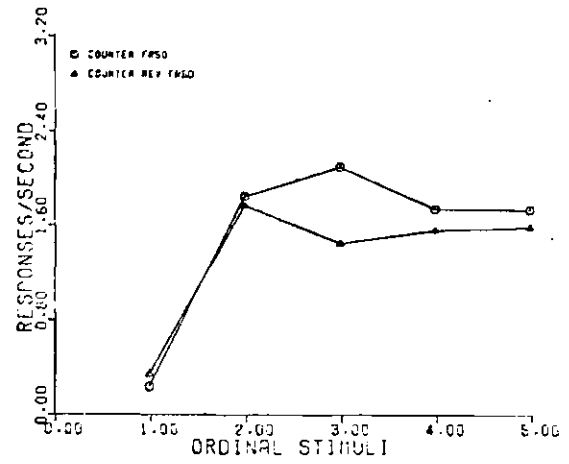


P289

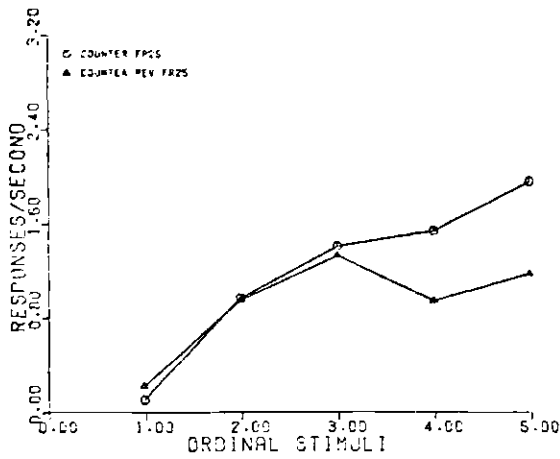
Figure 12. Response Rate in Each Counter and Clock Stimulus



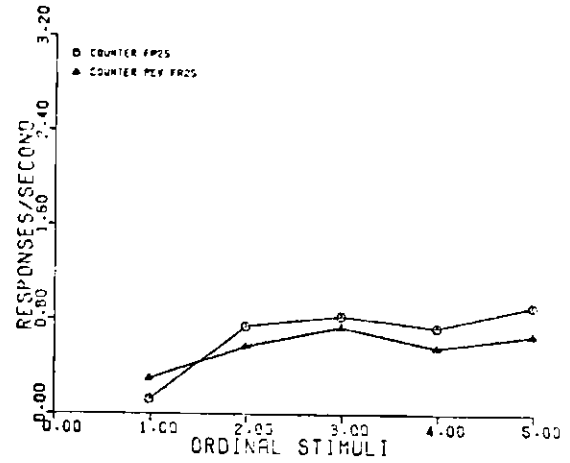
P8



P9

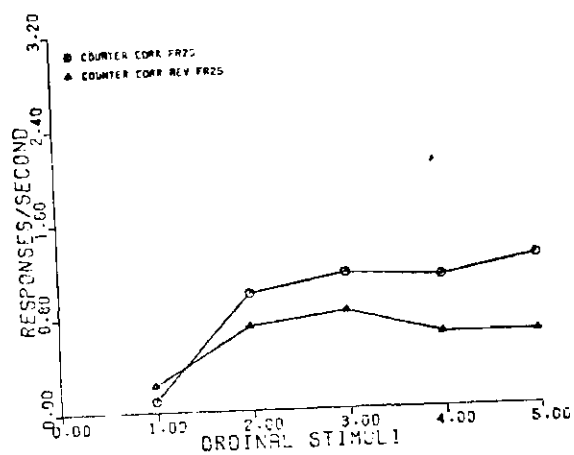


P70

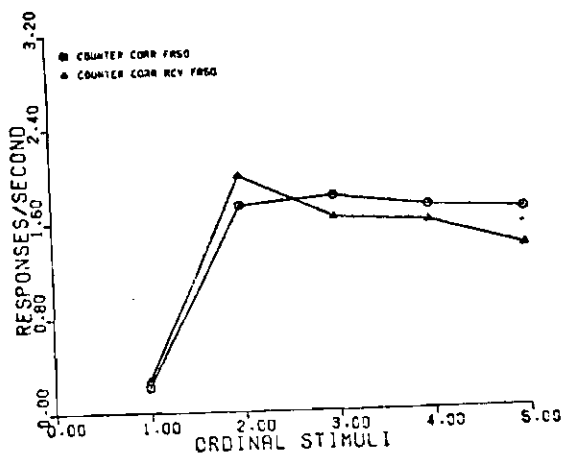


P289

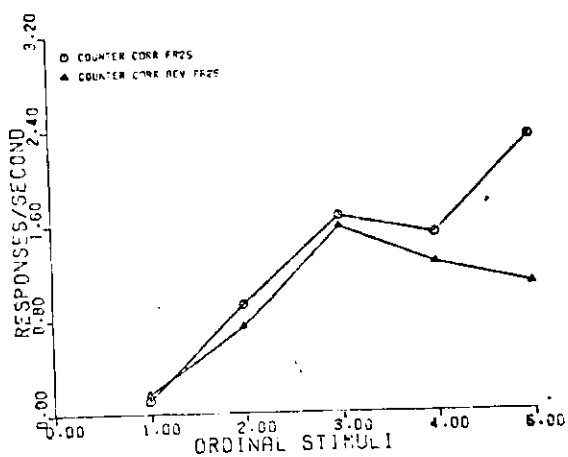
Figure 13. Response Rate in Counter and Counter Reversal



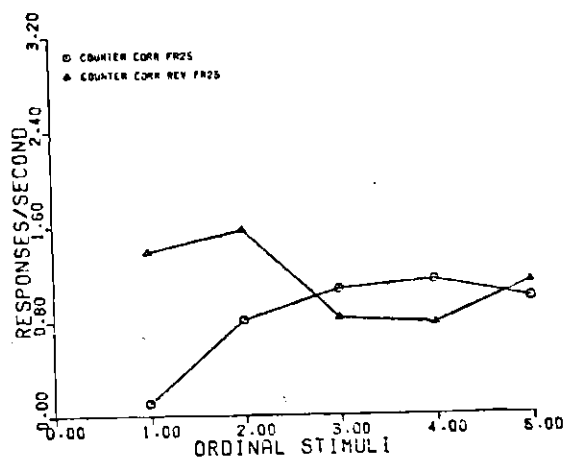
P8



P9

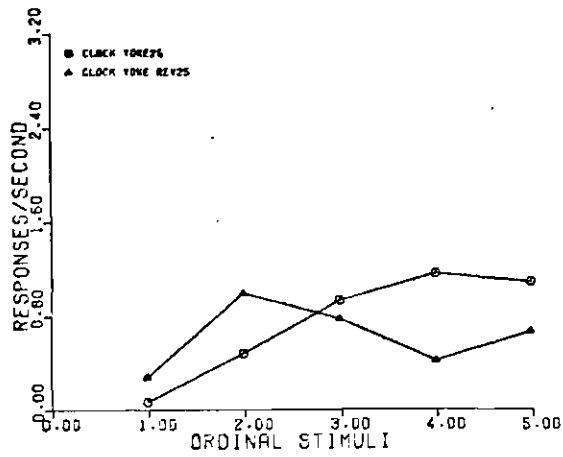


P70

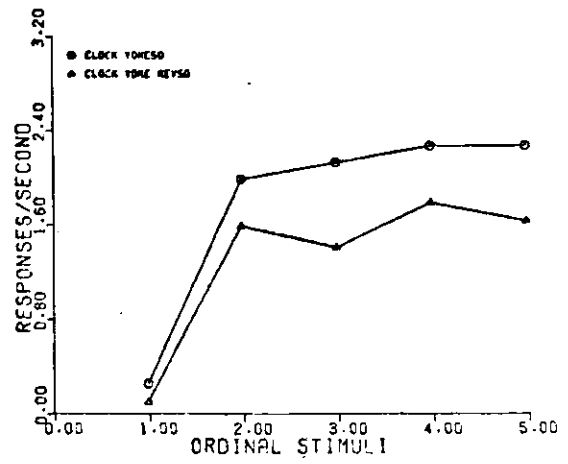


P289

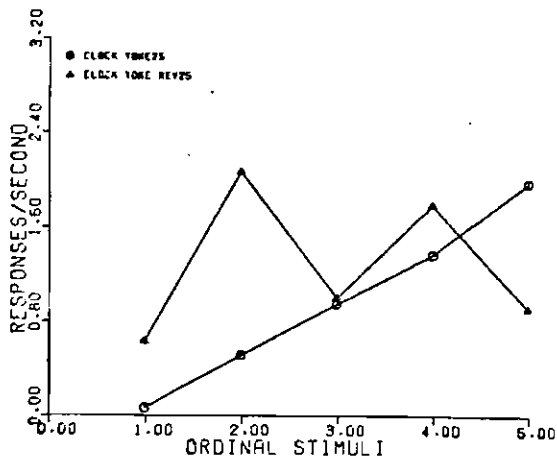
Figure 14. Response Rate in Counter with Correlated Reinforcement Rate



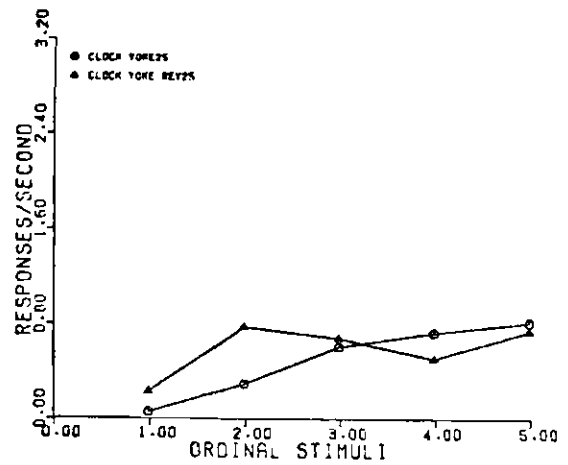
P8



P9



P70



P289

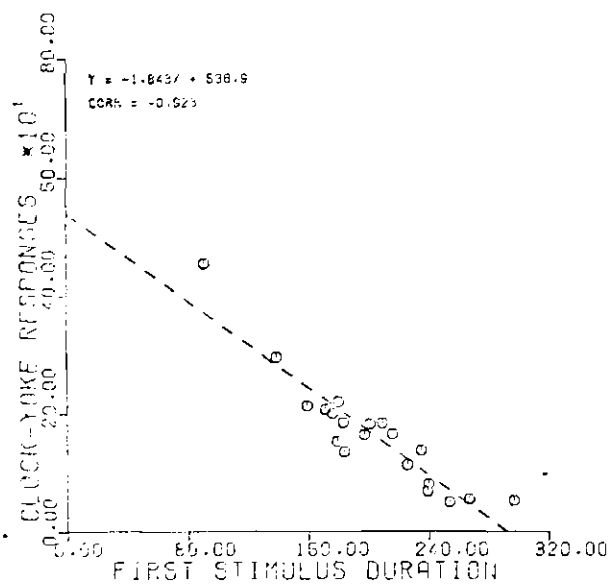
Figure 15. Response Rate in Clock and Clock Reversal

Clock Performance

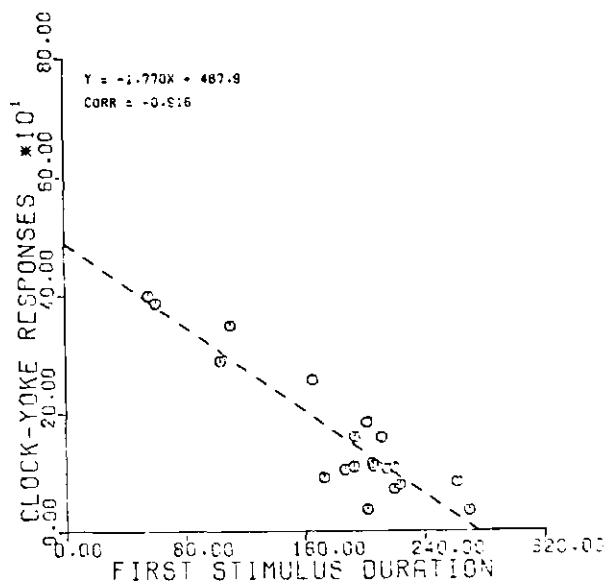
The last four sessions of condition VII were used as control sessions for a yoked-control experiment in which the counter stimulus durations were used as clock stimulus durations in condition VIII. Thus the rates of reinforcement in the presence of each stimulus were the same for the two conditions. The only difference was that under condition VII the stimuli changed as a function of response rate and under condition VIII the stimuli changed independently of responding.

As noted above, there was little change in behavior if the overall response rate, quarter life, or lag 1 autocorrelations are used for the comparisons. However, since the procedure involved yoking stimuli in one to performance in another condition, it was of interest to see how performance under the two conditions compared. It was found that the number of responses in each interval of the two sessions were highly correlated (ranging as high as $+0.98$). Since under condition VII with the counter a high response count in an interval was associated with shorter pause times, perhaps the control in the clock arrangement derived from the duration of the first stimulus.

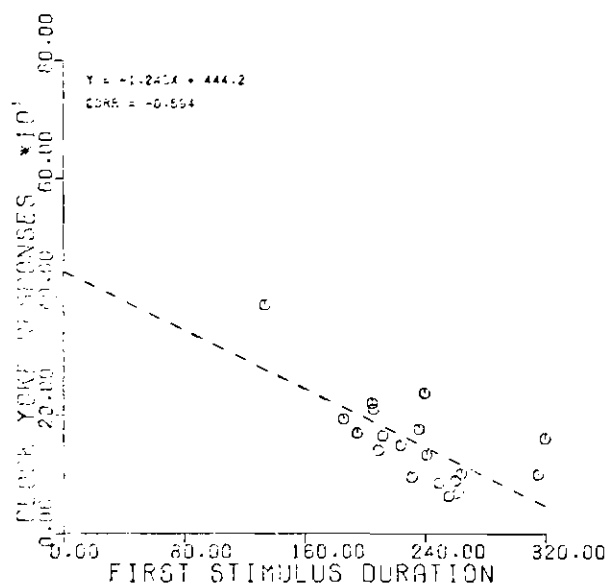
That the clock stimuli exerted powerful control over behavior was demonstrated by the high negative correlation between response number and the duration of the first stimulus of the clock. That is, when the stimulus changed early in the interval, there was a high response count in that interval. These data are shown in Fig. 16 for each of the four yoke-control sessions (A4, B4, C4, and D4) for each of the four pigeons. The correlations ranged from -0.475 to -0.925 . Thus, between 20 and 85



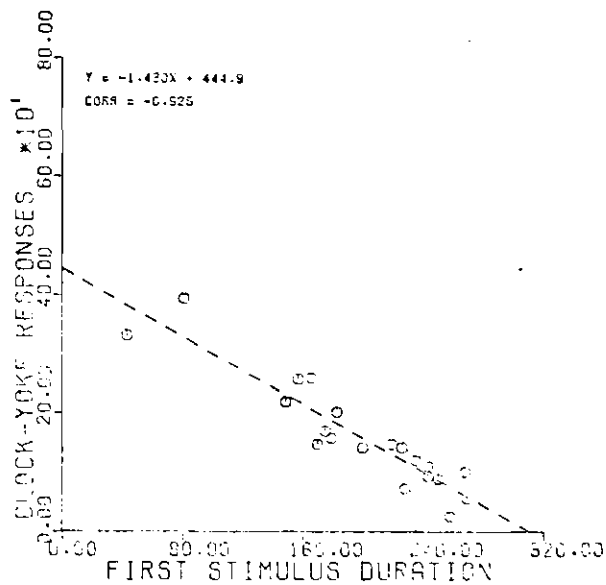
70A4



70B4

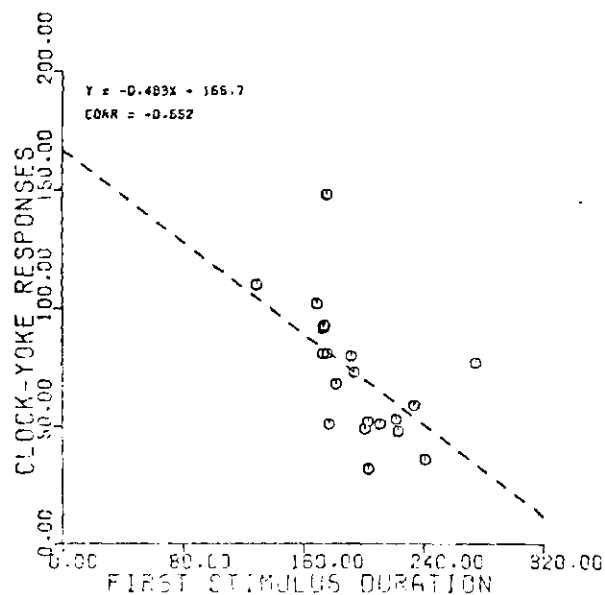


70C4

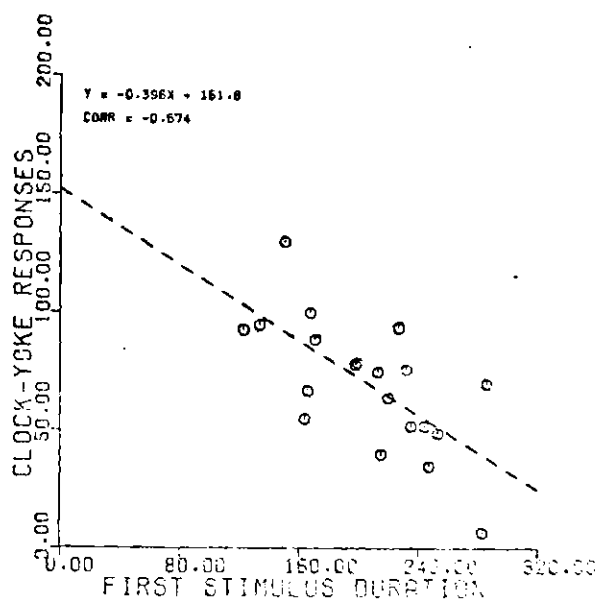


70D4

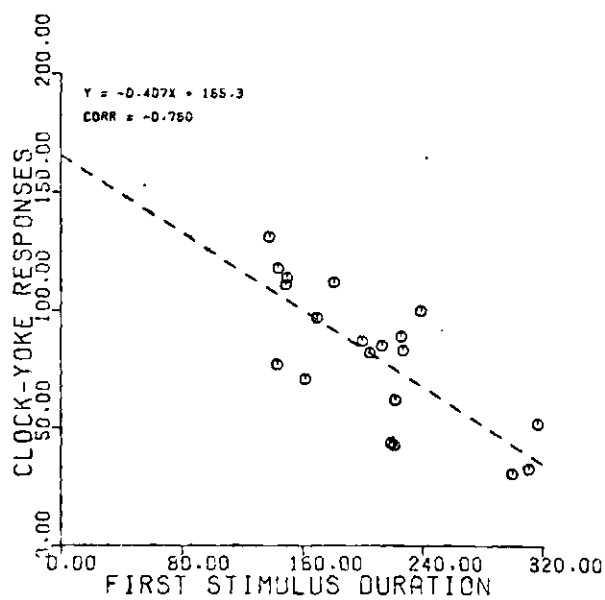
Figure 16. Response Number under Clock as a Function of First Stimulus Duration



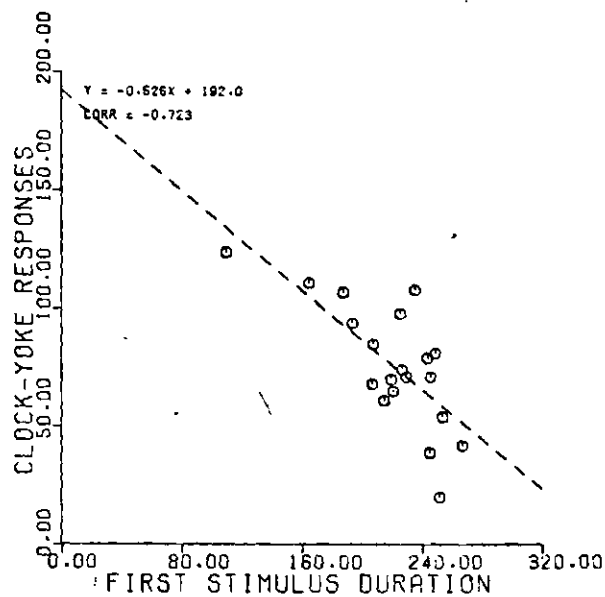
289A4



289B4

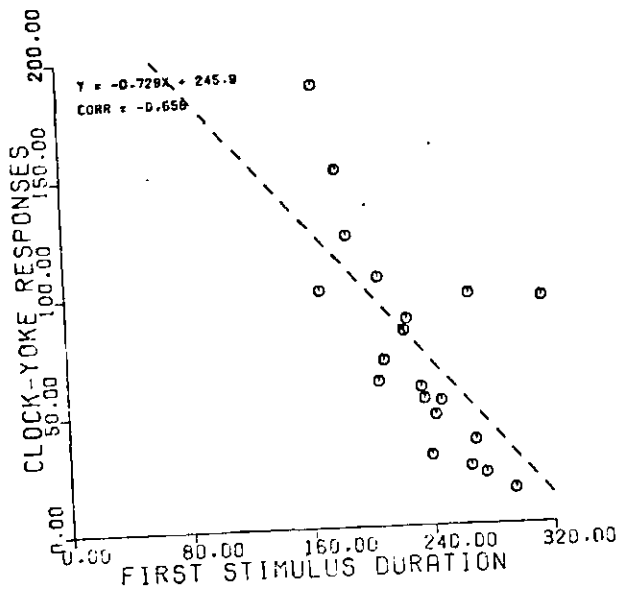


289C4

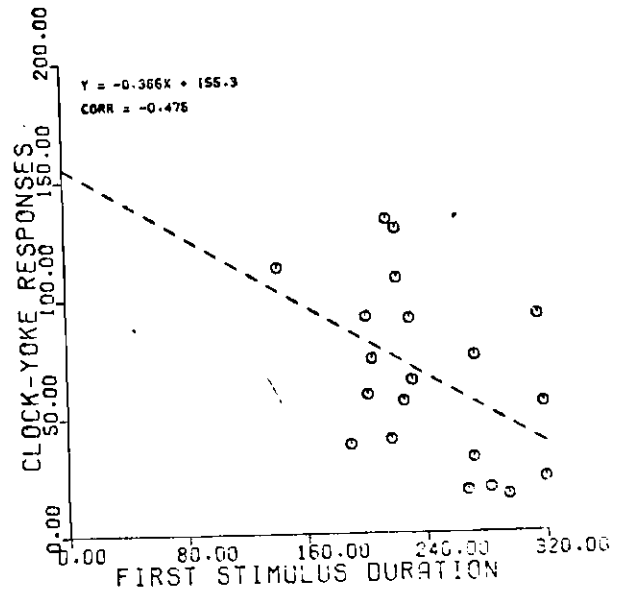


289D4

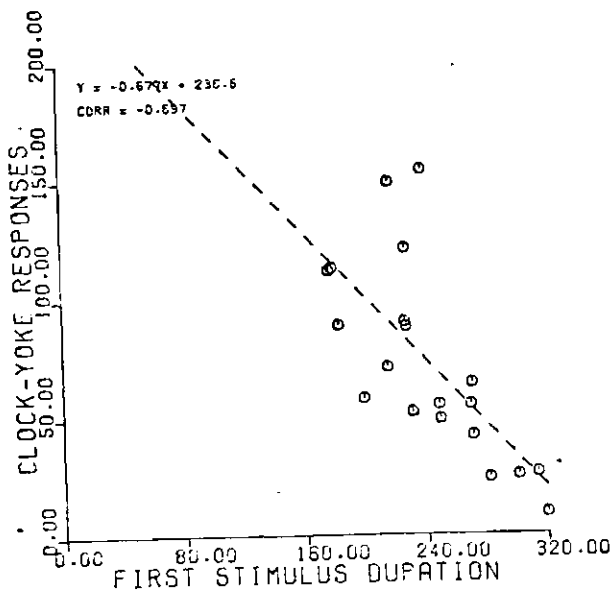
Figure 16. Continued



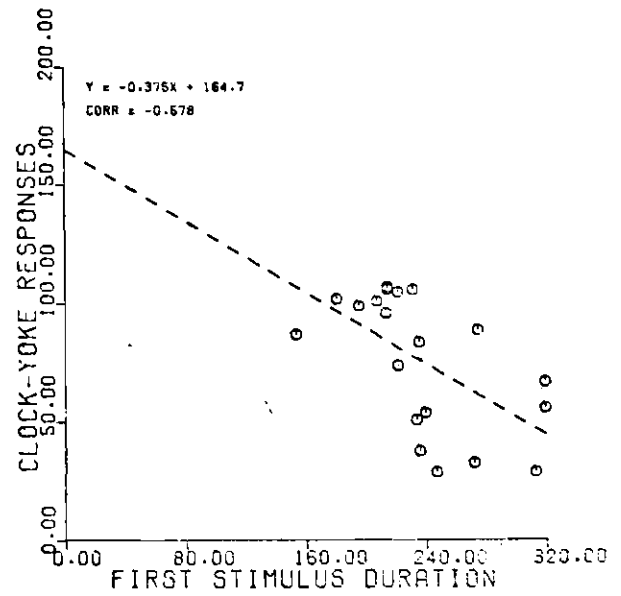
8A4



8B4

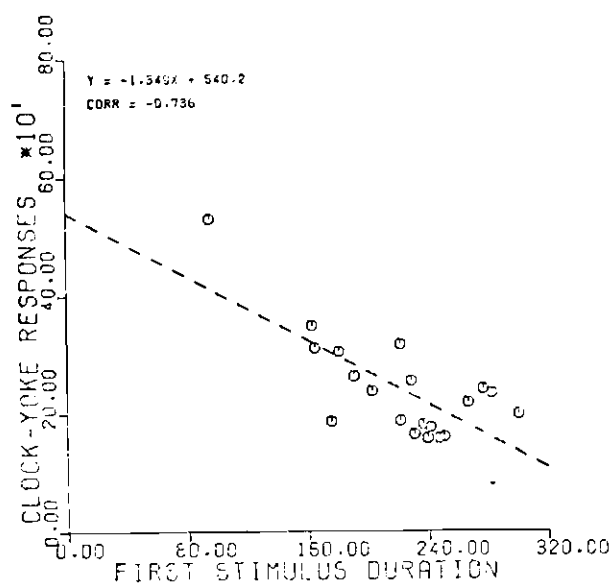


8C4

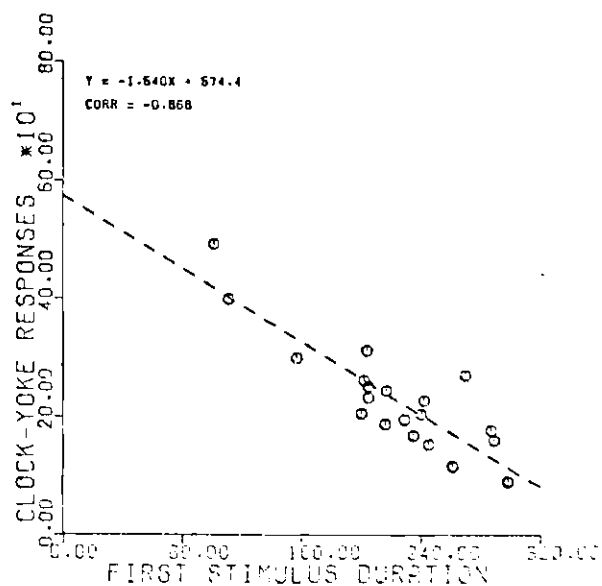


8D4

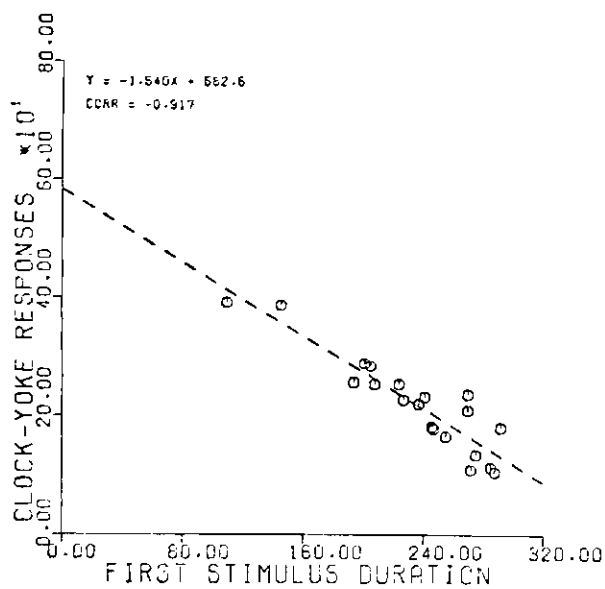
Figure 16. Continued



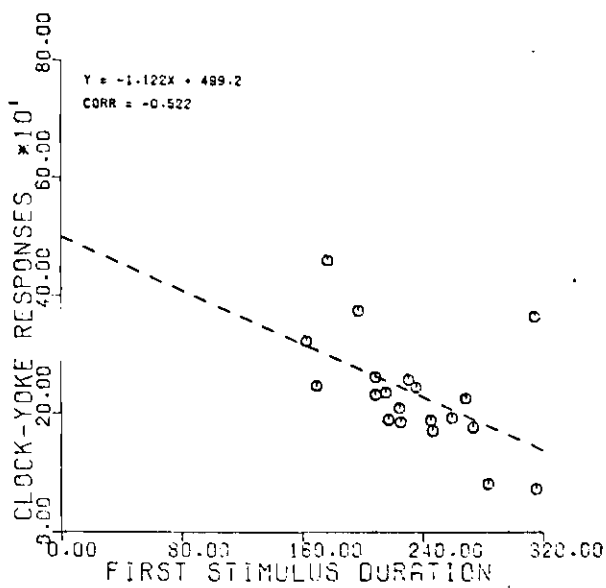
SA4



9B4



9C4



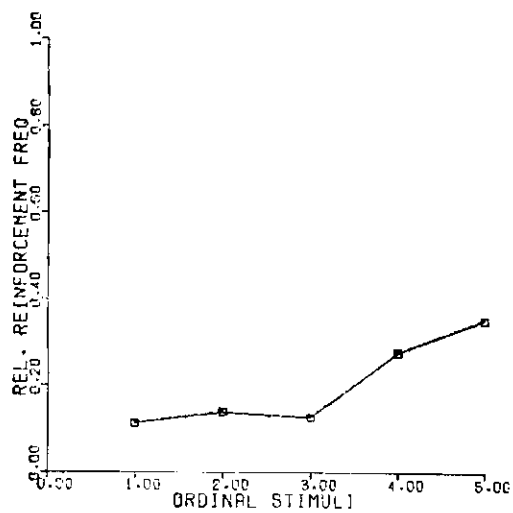
9D4

Figure 16. Continued

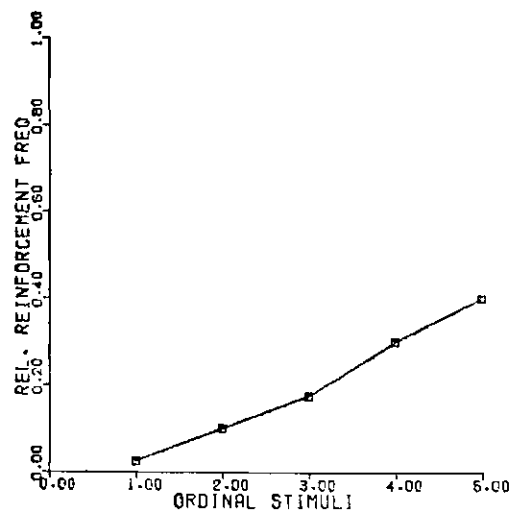
per cent of the variability in response number under the clock arrangement was accounted for by the duration of the first stimulus. P8 had the lowest correlation magnitude consistently and also had the highest frequency of reinforcement in the first stimulus. The data in Fig. 17 show that responding was maintained in the presence of the clock stimuli by low reinforcer frequencies (the data are presented as proportion of the 80 total reinforcers).

Cumulative Records

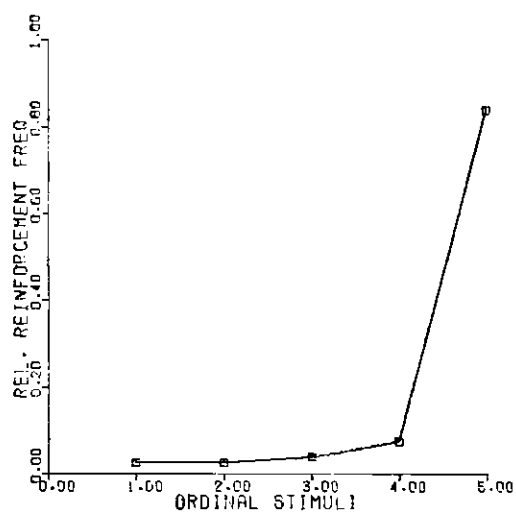
Representative cumulative records for each of the eight conditions for P70 are shown in Fig. 18. (Condition I record was made with a different gear arrangement on the recorder.) The similarity between the two yoked conditions is shown quite clearly by the records for VII and VIII.



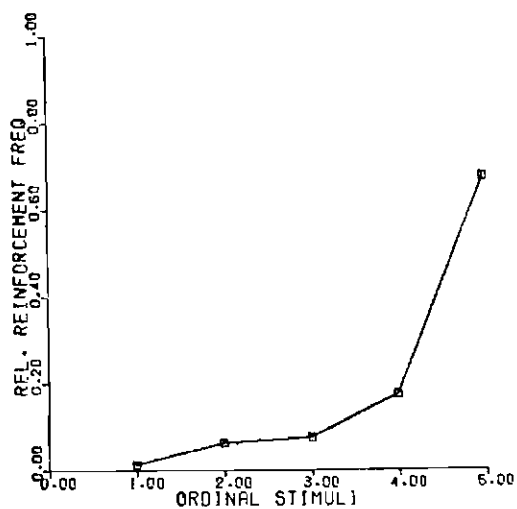
P8



P9



P70



P289

Figure 17. Proportion of Reinforcers in the Presence of the Clock Stimuli

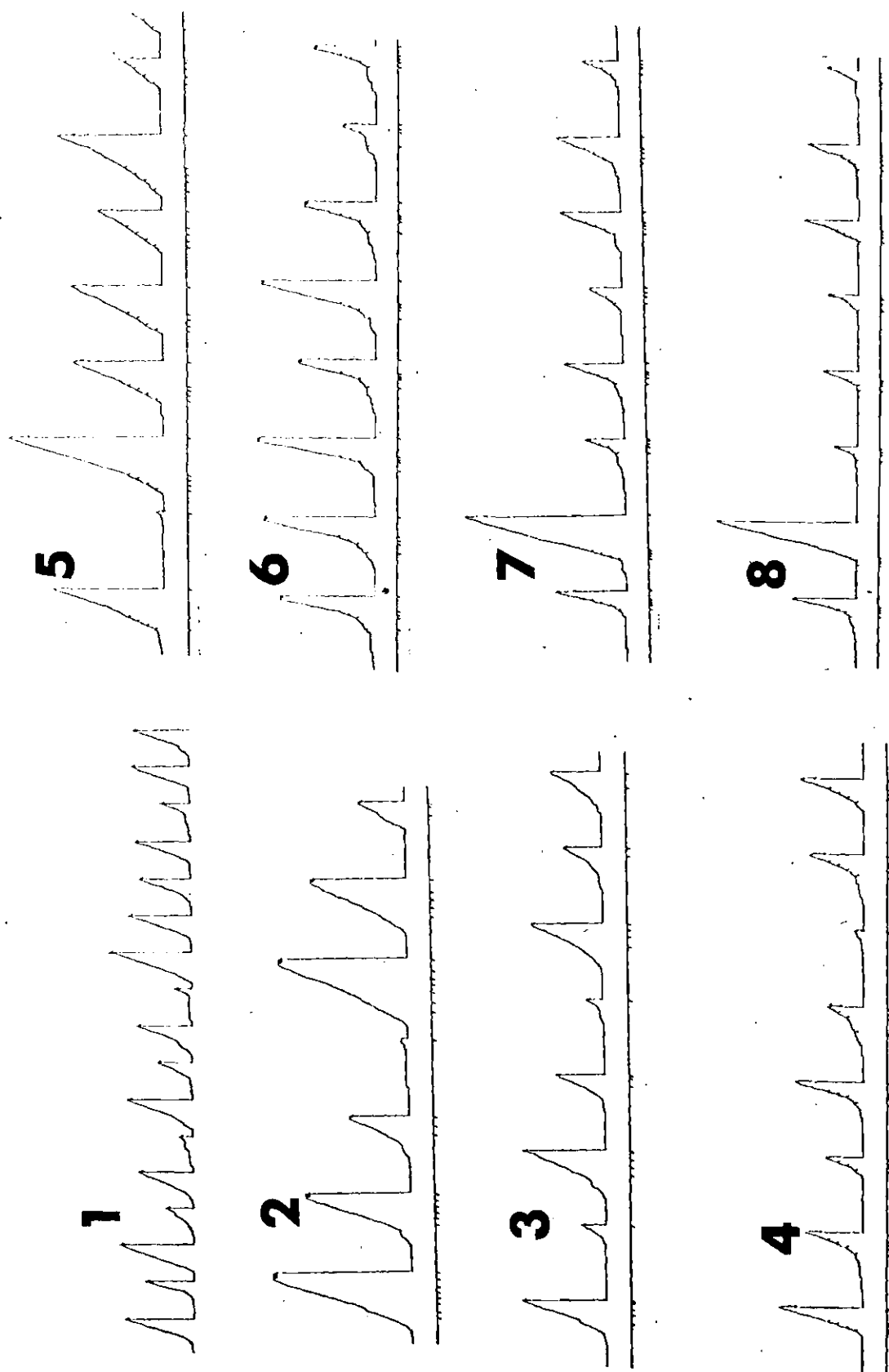


Figure 18. Cumulative Records for P70 over Conditions

CHAPTER V

DISCUSSION

The results presented in the preceding chapter largely reflect no change in behavior as a result of the experimental manipulations. However, these results do shed some light on the controlling aspects of FI schedules.

Responses Per Reinforcer

The role of the indirect variable responses per reinforcer appears to be negligible. Under condition II when it was held relatively constant at about 50 responses per reinforcer (100 for P9), the only consistent effect was an increase in quarter life, a measure of stereotypic performance under FI schedules. Under condition VI there was no consistent change when the correlation between response rate and reinforcement frequency was reinstated with the addition of a counter.

Previous work (e.g., Herrnstein and Morse, 1958) attributed control of the second-order deviations to responses per reinforcer. The lag 1 autocorrelations in the present study showed that the manipulation of the responses per reinforcer did not influence the second-order deviations in a consistent manner. Several interpretations of this negative finding are possible.

First, it is possible that the responses per reinforcer could be an effective indirect variable, but the parameters of the present study were not in the correct range for detecting its effectiveness. This

explanation does not seem tenable since as many as ten reinforcers were presented at the end of a high response count interval under condition II. Even when the ratio of responses per reinforcer was dropped to 25 (50 for P9) and a counter added under condition VI, the second-order deviations were not influenced.

Second, responses per reinforcer could be very effective in controlling behavior as a direct variable (as in the standard FR schedule) but only minimally effective under the present arrangement as an indirect variable. That is, relative to other controlling variables under FI schedules the influence of responses per reinforcer is not pronounced enough to be detected with the present procedures. This explanation seems unlikely since the consistent negative lag 1 autocorrelation was not altered by the manipulation of responses per reinforcer under conditions II and VI.

Third, since there was a consistent negative lag 1 autocorrelation and the manipulations of responses per reinforcer were ineffective, perhaps the variable of importance is simply response number. Under standard FI procedures, response number and responses per reinforcer are identical since there is only one reinforcer presentation per interval. Since the introduction of higher reinforcer frequencies did not alter the dynamics of responding as shown by the lag 1 autocorrelations, then response number is a more likely candidate for an effective indirect variable under FI schedules.

Thus, as a direct variable, responses per reinforcer may be very effective, as with FR schedules (Zeiler, 1977) or with a conjunctive FI

FR schedule (Herrnstein and Morse, 1958). But under FI schedules when operating as an indirect variable, responses per reinforcer is more likely ineffective and response number only slightly effective as the small lag 1 autocorrelations demonstrate.

Another result from conditions II and VI was that response rate did not increase, even though higher response rates were differentially reinforced with these two procedures. Correlation between responding and reinforcement is apparently not sufficient to increase rates as suggested by Baum (1973) and Rachlin (1976).

Response Number

If response number is an effective indirect variable under FI schedules, then the addition of a counter would make the control explicit. The counter was used in conditions IV and VII, and also in VI with the correlated reinforcement rate. Since response number in one interval controls (to a small degree) responding in the next interval, it was anticipated that making the explicit stimuli associated with response number available would enhance the effect of the variable, i.e., increase the magnitude of the negative lag 1 autocorrelation. This result did not occur.

Since response number is weakly effective in controlling behavior, either the counter was totally ineffective (i.e., did not control behavior) or the external counter was no more effective than control by behavior (and may have gained control of behavior). The response rates in the presence of each stimulus under conditions IV, VI, and VII show that there was no difference from standard FI responding when rates were

calculated as if the stimuli were present (condition V). So either of the above explanations is plausible. However, when the counter stimuli were reversed in order, changes in rates were observed. Therefore, the counter did gain control over behavior, but it was no more effective than control already present under standard FI procedures.

Since the response rates did not differ when comparing conditions IV, VI, and VII with condition V, it is not possible to ascribe conditioned reinforcing properties to the counter stimuli or to the production of count (Ferster and Skinner, 1958) beyond that found in standard FI arrangements.

Clock Stimuli

The fact that the counter stimuli could gain some control over responding under FI schedules indicates that behavior may function as a crude clock. However, since reversing the stimuli did not exactly reverse the pattern of FI responding, other variables are obviously operating. The low response rate that was typically found in the first of the reversed stimuli shows the powerful control exerted by the onset of other stimuli associated with the beginning of the interval. If time can be "measured" by amount of behavior that has occurred since the beginning of the interval, then, by providing the subject with a response-independent explicit stimulus version of its own behavior, control over behavior might be maintained. This was the procedure used in yoking conditions VII and VIII.

It was found that response number under the clock arrangement (condition VIII) was controlled to a large degree by the duration of the

first stimulus (which was determined under condition VII by the time it took to complete the first 25 responses for P8, P70, and P289, or 50 responses for P9). Thus it is plausible that the variable "amount of behavior since interval onset" can control momentary response rates under FI schedule. The intuitive appeal of this potential variable is that if response number can exert even weak control from one interval to the next, then more powerful control could be exerted by the same variable within an interval. However, the effectiveness of the variable cannot be verified with the present data for two reasons. First, behaviors other than key pecks were not monitored. Second, within-interval changes in response rates (third-order deviations) were not measured.

Conclusions

These results indicate that FI behavior, both stereotypic and dynamic, is relatively unresponsive to the experimental manipulations that were performed. The data showed that response number can exert influence from one interval to next, but the influence is weak. Behavior in an interval seems to be controlled largely by the stimulus conditions prevailing at the time of interval onset; thereafter, it is possibly controlled by an irregular behavioral clock.

Recommendations for Future Research

The clock condition of this experiment indicated strong control over responding by the stimulus associated with interval onset. Since the clock stimulus changes were yoked to stimulus changes under counter

performance, the arrangement may have been optimum for demonstrating this effect. In addition to stimulus changes that were equivalent to what the pigeon would have produced by its own behavior, the second-order deviations engendered under the clock arrangement were also equivalent to that which was engendered under the counter. Thus, the high negative correlation between response number and first stimulus duration may be the direct result of the yoking procedure. Clock stimulus durations could be constructed to test this hypothesis. By selecting first stimulus durations that are not representative of counter performance and by arranging them in a sequence to produce various lag 1 autocorrelations, there should be a decrease in amount of variability in response number accounted for by the first stimulus duration.

Another aspect of the FI schedule with an irregular clock that needs to be investigated is the determination of response rate in the presence of each of the stimuli as a function of frequency of reinforcement in the presence of each stimulus. In the present study reinforcement did occur in the presence of each of the five stimulus (as determined by counter performance). It is possible that control by the first stimulus would have been sharper if reinforcement never occurred in its presence.

Second-order deviations should also be explored with different procedures and schedule parameters. As noted before very little quantitative data are available on the magnitude of this effect. The lag 1 autocorrelations could be determined to some extent by the parameter of the FI schedule and by events intervening between two

successive intervals. FI 5 min. as in this study may not be the optimum value for studying second-order deviations. In addition, this study had a 1 min. blackout between intervals. Perhaps the magnitude of the negative lag 1 autocorrelations would be increased by eliminating all stimulus events (including blackouts) occurring between the intervals. Conversely, by providing various stimulus events between two intervals (e.g., "free" reinforcers or another schedule), the lag 1 autocorrelations might be eliminated.

References

- Baum, W.M. The correlation-based law of effect. Journal of the Experimental Analysis of Behavior, 1973, 20, 137-154.
- Bolles, R.C. Theory of Motivation, New York: Harper, 1975.
- Dews, P.B. The effect of multiple Δ periods on responding on a fixed-interval schedule. Journal of the Experimental Analysis of Behavior, 1962, 5, 369-374.
- Dews, P.B. The effect of multiple Δ periods on responding on a fixed-interval schedule: In a primate. Journal of the Experimental Analysis of Behavior, 1965, 8, 53-54. (a)
- Dews, P.B. The effect of multiple Δ periods on responding on a fixed-interval schedule. III. Effect of changes in patterns of interruptions, parameters, and stimuli. Journal of the Experimental Analysis of Behavior, 1965, 8, 427-435. (b)
- Dews, P.B. The effect of multiple Δ periods on responding on a fixed-interval schedule. IV. Effect of continuous Δ with only short periods of SD probes. Journal of the Experimental Analysis of Behavior, 1966, 9, 147-155. (a)
- Dews, P.B. The effect of multiple Δ periods on responding on a fixed-interval schedule. V. Effect of periods of complete darkness and occasional omissions of food presentation. Journal of the Experimental Analysis of Behavior, 1966, 9, 573-578. (b)
- Dews, P.B. Studies on responding under fixed-interval schedules of reinforcement: The effects on the pattern of responding of changes in requirements at reinforcement. Journal of the Experimental Analysis of Behavior, 1969, 12, 191-200.
- Dews, P.B. The theory of fixed-interval responding. In W.N. Schoenfeld (Ed.), The Theory of Reinforcement Schedules, New York: Appleton-Century-Crofts, 1970, 43-61.
- Dimond, S.J. The structural basis of timing. Psychological Bulletin, 1964, 62, 348-350.
- Farmer, J. and Schoenfeld, W.N. Varying temporal placement of an added stimulus in a fixed-interval schedule. Journal of the Experimental Analysis of Behavior, 1966, 9, 369-376.

- Ferster, C.B. and Skinner, B.F. Schedules of Reinforcement. New York: Appleton-Century-Crofts, 1957.
- Herrnstein, R.J. and Morse, W.H. A conjunctive schedule of reinforcement. Journal of the Experimental Analysis of Behavior, 1958, 1, 15-23.
- Laties, V.G. The role of discriminative stimuli on modulating drug action. Federation Proceedings, 1975, 34, 1880-1888.
- Laties, V.G. and Weiss, B. Influence of drugs on behavior controlled by internal and external stimuli. Journal of the Experimental Analysis of Behavior, 1966, 152, 388-396.
- Laties, V.G., Weiss, B., Clark, R.L., and Reynolds, M.D. Overt "mediating" behavior during temporally spaced responding. Journal of the Experimental Analysis of Behavior, 1965, 8, 107-116.
- Laties, V.G., Weiss, B., and Weiss, A.B. Further observations on overt "mediating" behavior and the discrimination of time. Journal of the Experimental Analysis of Behavior, 1969, 12, 43-57.
- Marr, M.J. Sequence schedules of reinforcement. Journal of the Experimental Analysis of Behavior, 1971, 15, 41-48.
- Meltzer, D. and Brahlek, J.A. Quantity of reinforcement and fixed-interval performance. Psychonomic Science, 1968, 12, 207-208.
- Meltzer, D. and Brahlek, J.A. Quantity of reinforcement and fixed-interval performance: Within-subject effects. Psychonomic Science, 1970, 20, 30-31.
- Morse, W.H. Intermittent reinforcement. In W.K. Honig (Ed.), Operant Behavior: Areas of research and application, New York: Appleton-Century-Crofts, 1966.
- Rachlin, H. Behavior and Learning. San Francisco: Freeman, 1976.
- Schneider, B.A. A two-state analysis of fixed-interval responding in the pigeon. Journal of the Experimental Analysis of Behavior, 1969, 12, 677-688.
- Segal, E.F. Exteroceptive control of fixed-interval responding. Journal of the Experimental Analysis of Behavior, 1962, 5, 49-56.
- Shull, R.L. The response-reinforcement dependency in fixed-interval schedules of reinforcement. Journal of the Experimental Analysis of Behavior, 1970, 14, 55-60.

- Shull, R.L. Sequential patterns of post-reinforcement pauses on fixed-interval schedules of food. Journal of the Experimental Analysis of Behavior, 1971, 15, 221-230.
- Skinner, B.F. The Behavior of Organisms. New York: Appleton-Century-Crofts, 1938.
- Skinner, B.F. Operant behavior, In W.K. Honig (Ed.), Operant Behavior: Areas of research and application, New York: Appleton-Century-Crofts, 1966.
- Staddon, J.E.R. Effect of reinforcement duration on fixed-interval responding. Journal of the Experimental Analysis of Behavior, 1970, 13, 9-12.
- Stebbins, W.C., Mead, P.B., and Martin, J.M. The relation of amount of reinforcement to performance under a fixed-interval schedule. Journal of the Experimental Analysis of Behavior, 1959, 2, 351-356.
- Zeiler, M.D. Schedules of reinforcement. In W.K. Honig and J.E.R. Staddon (Eds.), Handbook of Operant Behavior, New York: Appleton-Century-Crofts, 1977.

VITA

George David Gentry
School of Psychology
Georgia Institute of Technology
Atlanta, Georgia 30332

Born November 30, 1945
Florence, Alabama

Academic History

B.A.E. 1963-1969 - Georgia Institute of Technology
Major: Aerospace Engineering, Co-operative Plan

1970-1971 - University of Houston, Houston, Texas

M.S. 1971-1975 - Georgia Institute of Technology
Thesis: Two-Key Concurrent Responding: Choice and delay of reinforcement at constant relative immediately or reinforcement.
Specialization: Conditioning, learning, and cognitive processes.
Minor: Mathematics

Ph.D. 1975-1978 - Georgia Institute of Technology
Major: General Experimental Psychology
Minor: Mathematics
Dissertation: Response Number Under a Fixed-Interval Schedule of Reinforcement.